1985
Hay River Flood Report
N.W.T.

Environnement Canada
Conservation et Protection

Environment Canada
Conservation and Protection

Canada

1985
Hay River Flood Report
N.W.T.

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Water Planning & Management

Yellowknife, N.W.T.

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Inland Waters Directorate
Conservation & Protection
Western & Northern Region
Environment Canada

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Cover Photo courtesy of Murray Jones.

The West Channel Fishing Village underwater, mid-morning, May 7, 1985. Note the limit of flood debris impounded behind offshore pressure ridge.

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Abstract

This report chronicles the flood events in the town of Hay River in early May, 1985. The natural causes for the flood are analysed. Recommendations derived from these analyses make suggestions for design of flood warning systems. They also recommend the redesignation under the Flood Damage Reduction Program of the Hay River flood plain on Vale Island.

Résumé

Ce rapport documente les événements entourant l'inondation survenue au début du mois de mai 1985, dans le village de Hay River. Les causes naturelles génératrices de cette crue sont analysées. Basés sur ces analyses, les recommendations faites suggèrent l'élaboration de systèmes d'avertissement en cas de crues. Il est de plus recommendé que l'île Vale située sur la zone inondable de la rivière Hay soit désignée à nouveau en vertue du Programme pour la réduction des dommages dûs aux inondations.

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HAY RIVER FLOOD

1.0 INTRODUCTION

Inland Waters Directorate of Environment Canada has systematically reported on floods of national significance in Canada. Although the perennial flooding of the town of Hay River might not be considered to be of national significance in terms of economic loss, it is of some concern because Hay River town has been mapped under the national Flood Damage Reduction Program with Canada Water Act funding and because the river system causing the floods is an interjurisdictional waterway. The bulk of its basin, as shown in Figure 1, is in Alberta. Systematic reporting of major floods provides reliable information against which to compare future events. Such comparisons are of interest to social economists as well as to scientists who research water and ice phenomena. Good flood reporting is essential to the making of sound decisions by local, territorial and federal planners. The NWT portion of the basin is detailed in Figure 2.

The 1985 flood in the town of Hay River in early May was considered to be a significant event because of its life-threatening potential, because of the extensive damages it wrought and because of its differences from the major flood in 1963 which was used, in part, as the basis for designation of flood-prone areas in Hay River.

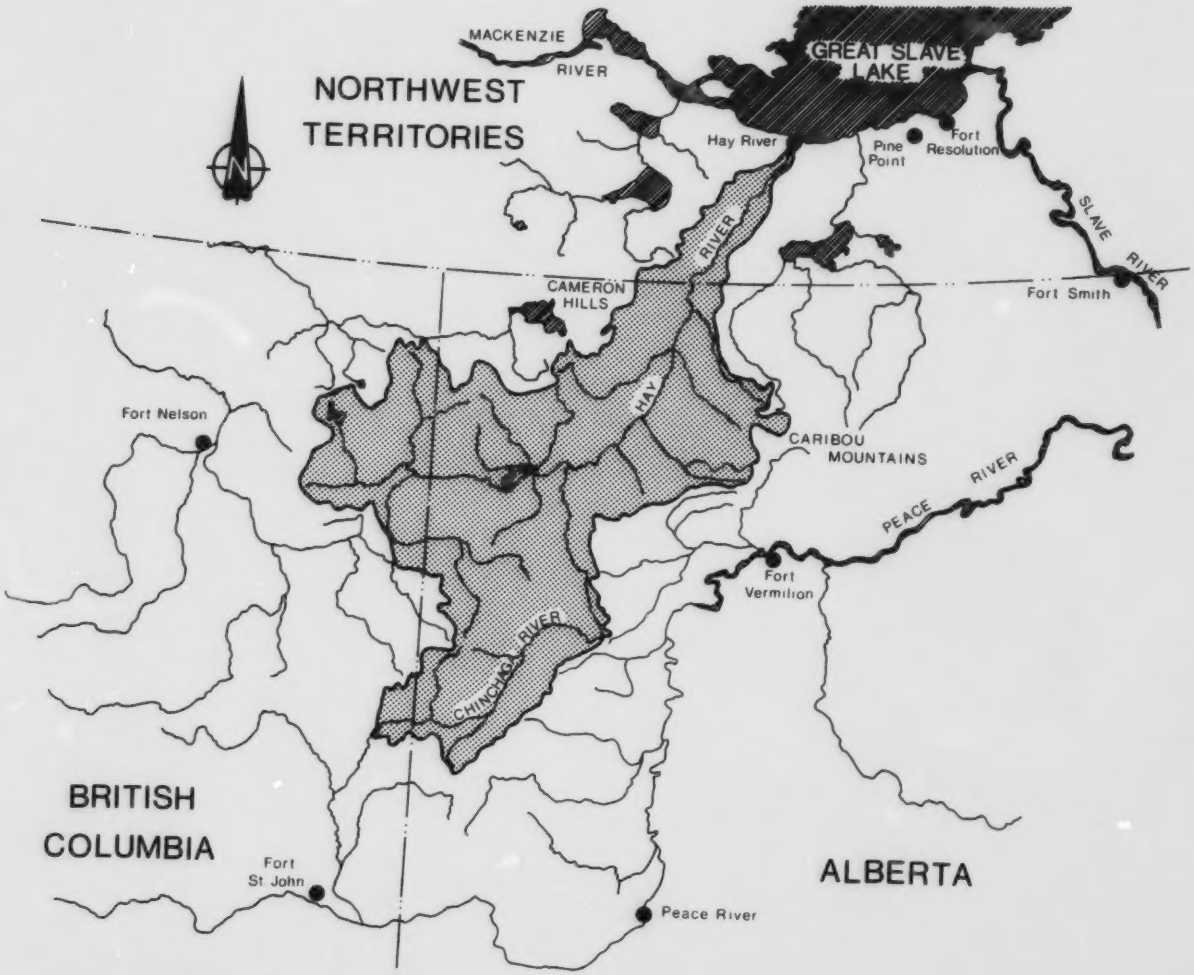

MACKENZIE
RIVER
NORTHWEST
TERRITORIES
N
GREAT SLAVE
LAKE
Hay River
Pine
Point
Fort
Resolution
SLAVE
RIVER
Fort Smith
RIVER
CAMERON
HILLS
HAY
Fort Nelson
CARIBOU
MOUNTAINS
PEACE
RIVER
Fort
Vermilion
CHINCHAGA RIVER
BRITISH
COLUMBIA
Fort
St John
ALBERTA
Peace River

Figure 1. Location of Hay River Basin (source, DIAND Water Resources)

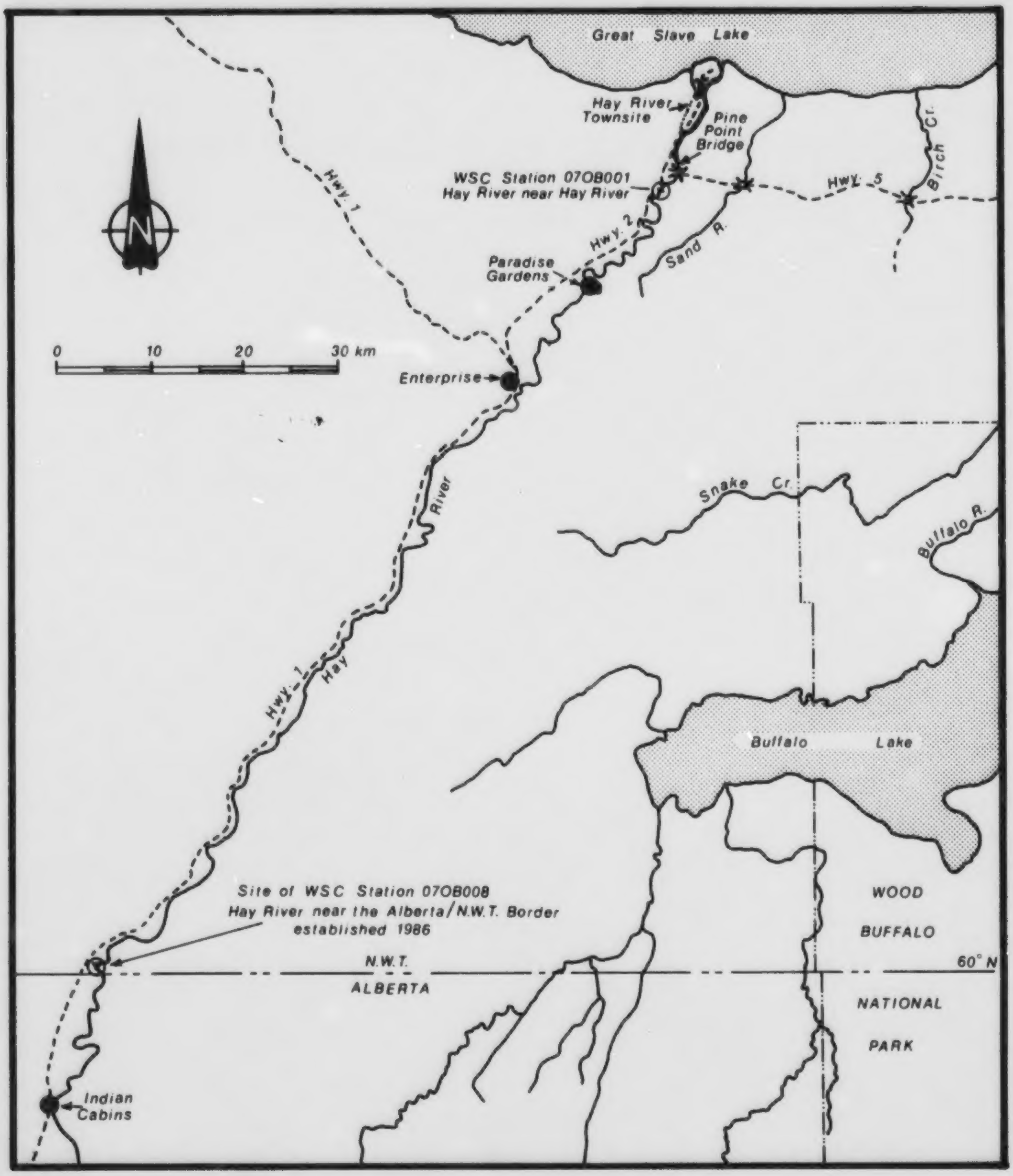

Great Slave Lake
Hay River Townsite
Pine Point Bridge
WSC Station 07OB001
Hay River near Hay River
Hwy. 5
Birch Cr.
Hwy. 1
Hwy. 2
Sand R.
N
Paradise Gardens
0
10
20
30 km
Enterprise
Snake Cr.
Buffalo R.
River
Hay
Hwy. 1
Buffalo Lake
Site of WSC Station 07OB008
Hay River near the Alberta/N.W.T. Border
established 1986
WOOD
BUFFALO
NATIONAL
PARK
60° N
N.W.T.
ALBERTA
Indian Cabins

Figure 2. Lower Hay River Basin

2.0 LOCATION

The town of Hay River is situated on the estuary of Hay River on the south shore of Great Slave Lake at 60°49'N latitude and 115°47'W longitude (NWT Data Book, 1986). Figure 3 is a sketch map of the town which identifies a number of the principal features or structures alluded to in this report. Physiographically, the town of Hay River is situated on the estuary of the Hay River drainage system. Vale Island is in fact, a deltaic structure. A number of ancient water courses on the island are still significant features which become active channels in floods. Surface materials are typical of deltaic environments - unconsolidated materials in the fine gravel, sand and silt range. Such materials are susceptible to extensive erosion in the absence of protection from root mats or other, man-made structures.

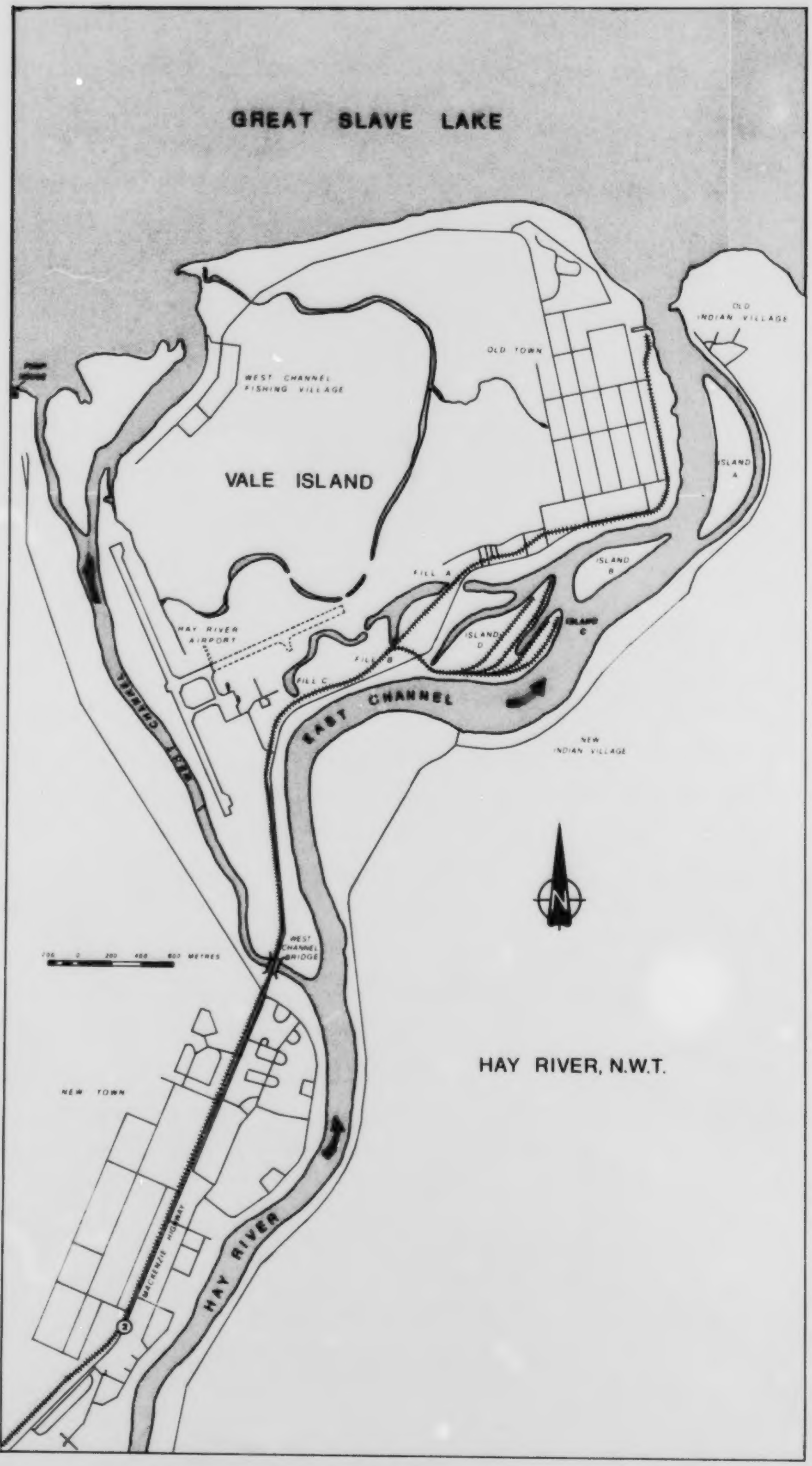

GREAT SLAVE LAKE
WEST CHANNEL FISHING VILLAGE
VALE ISLAND
OLD TOWN
OLD INDIAN VILLAGE
ISLAND A
ISLAND B
ISLAND C
ISLAND D
FILL A
FILL B
FILL C
HAY RIVER AIRPORT
EAST CHANNEL
WEST CHANNEL
NEW INDIAN VILLAGE
N
WEST CHANNEL BRIDGE
200 0 200 400 600 METRES
NEW TOWN
MACKENZIE HIGHWAY
HAY RIVER
HAY RIVER, N.W.T.

Figure 3. Hay River Townsite and Locations

3.0 FLOODING HISTORY

With the exception of the 1963 and 1974 floods, where personal recollections and photographs are still readily available, the most consistent historical records are those kept by Roman Catholic and Anglican missions. Translation of these historical descriptions has been difficult because references are often to buildings, roads or other landmarks no longer in existence. The Social Studies Class, 8C, (1978) of Diamond Jenness Secondary School in Hay River has compiled a most useful summary of historical floods. From this source and from previous work (Stanley, Grimble, Roblin Ltd., 1963; Underwood McLellan, 1978; IWD, 1983) it can be shown that major floods before 1985 occurred in 1887, 1914, 1934, 1963 and 1974. Less severe but still noteworthy floods were noted for the years 1904, 1911, 1947 and 1951. Without fail, the catastrophic and intermediate flood events with significant impact on Hay River community were associated with spring breakup of river ice and snowmelt high water. Blench in Stanley (1963) and Underwood McLellan (1978) identify a third contributing factor to Hay River floods - that of intact, solid ice offshore in Great Slave Lake. The significant historical floods have been tentatively assigned maximum elevations by Water Resources Division, DIAND, and were based on field surveys of ground elevations of specific locations identified in historical literature or by eyewitness accounts (Jasper, 1983). They are shown in Figure 4 as elevations obtained at various locations in Hay River and then related to estimates for flood levels at the old Indian Village. A tabular summary of these historic events is attached in Appendix A.

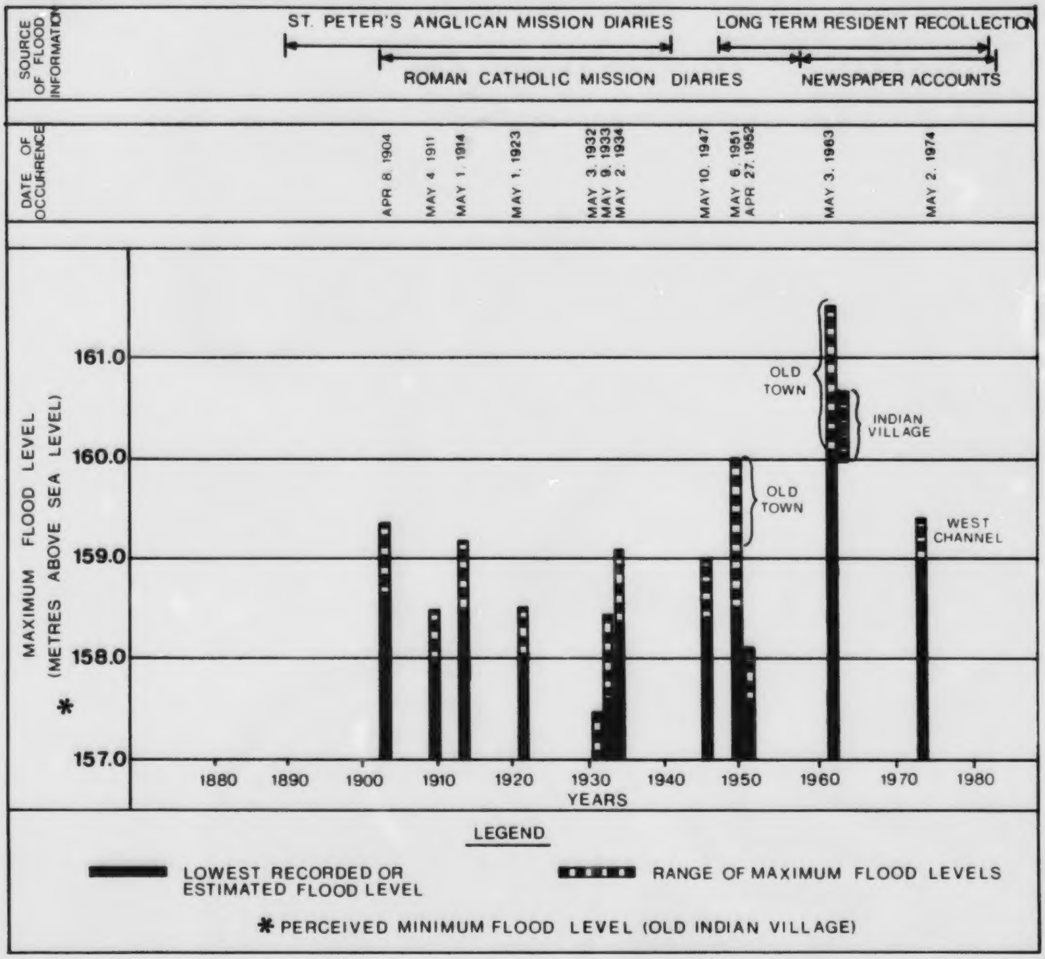


Figure 4. Historical Flood Levels, Hay River, N.W.T.
(from Jasper, 1983)

4.0 EXTENT OF FLOODING IN 1985

The impacts of the 1985 flood were concentrated along the West Channel in the Hay River estuary. West Channel flows are not well documented historically because most of the people live along the East Channel, the principal waterway around Vale Island to Great Slave Lake. This channel is wider and deeper than West Channel. Since the West Channel has a much higher bed elevation, it requires a high water level to allow passage of ice jams. Intact ice on the East Channel in the vicinity of the ice road to the Indian Village withstood ice jam loading in the early phases of the 1985 flood. The stable ice sheet in East Channel and the record high flows of May 6, 7 and 8 combined to create a very severe flood along the West Channel and near the lakeshore in the West Channel Fishing Village. In part, the Fishing Village flooding was caused by grounded ice jams in the near-shore of Great Slave Lake; the jamming on the lakeshore initiated by a pressure ridge arcing across the West Channel confluence.

A sketch map was prepared during an aerial survey flown by Water Survey of Canada (WSC) personnel on the morning of May 7, after the flood had begun to recede. Figure 5 is based on this map and documents the situation as it was at 10:00 of that day.

A post-flood engineering survey (Underhill Eng. Ltd., 1985) obtained point elevations of maximum water levels for affected parts of Hay River and vicinity. Point elevations and water level contours were developed on a series of 1:4000 map sheets by DIAND, Yellowknife

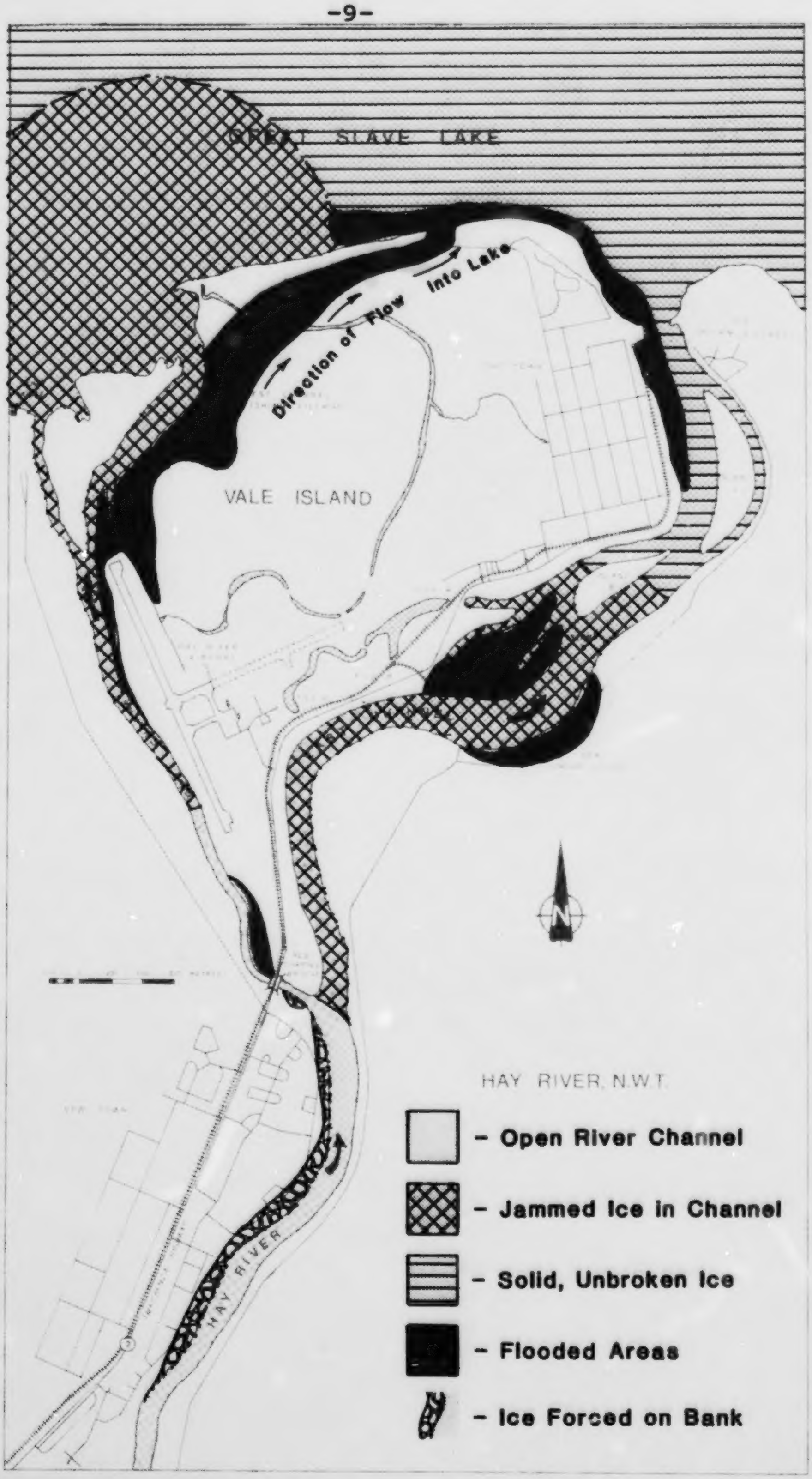

GREAT SLAVE LAKE
Direction of Flow Into Lake
VALE ISLAND
N
HAY RIVER
HAY RIVER, N.W.T.
□ - Open River Channel
▦ - Jammed Ice in Channel
▤ - Solid, Unbroken Ice
■ - Flooded Areas
- Ice Forced on Bank

Figure 5. Hay River Flood Situation, 10:00, May 7, 1985, Floodwaters Receding (from sketch map on telephone book street map used in helicopter survey by WSC)

technical staff. Extent of flooding is shown on Figure 6.

A earlier map of flooding in Hay River was drawn by the NWT Technical Committee of the Flood Damage Reduction Program. These data were obtained from the 1963 and 1974 floods and the subsequent flood risk map received wide circulation. A reproduction of it is enclosed in the back cover pocket of this report.

The extent of flooding in 1985 is combined with the Flood Damage Reduction (FDR) map in Figure 7. The two floods in 1963 and 1985 are totally different; in 1963 Vale Island suffered an East Channel flood and in 1985, a West Channel flood. The reasons for these differences are speculative - no firm engineering/hydraulic theories have as yet been developed. Certain isolated facts are known, however, which may eventually contribute to a scientific explanation for these significant flood differences. They are as follows:

1) In 1963, the ice jam moved out to the lake shore in the East Channel whereas in 1985, the ice jammed in the East Channel reach just below Vale Island bridge.

2) No flow data exists for 1963, but the flows in 1985 were a new record high.

3) The stream bed in West Channel is at a higher elevation than the main channel in the East Channel and therefore the West Channel requires a greater volume of flow and a higher water level to become a competent river channel, ie., one capable of

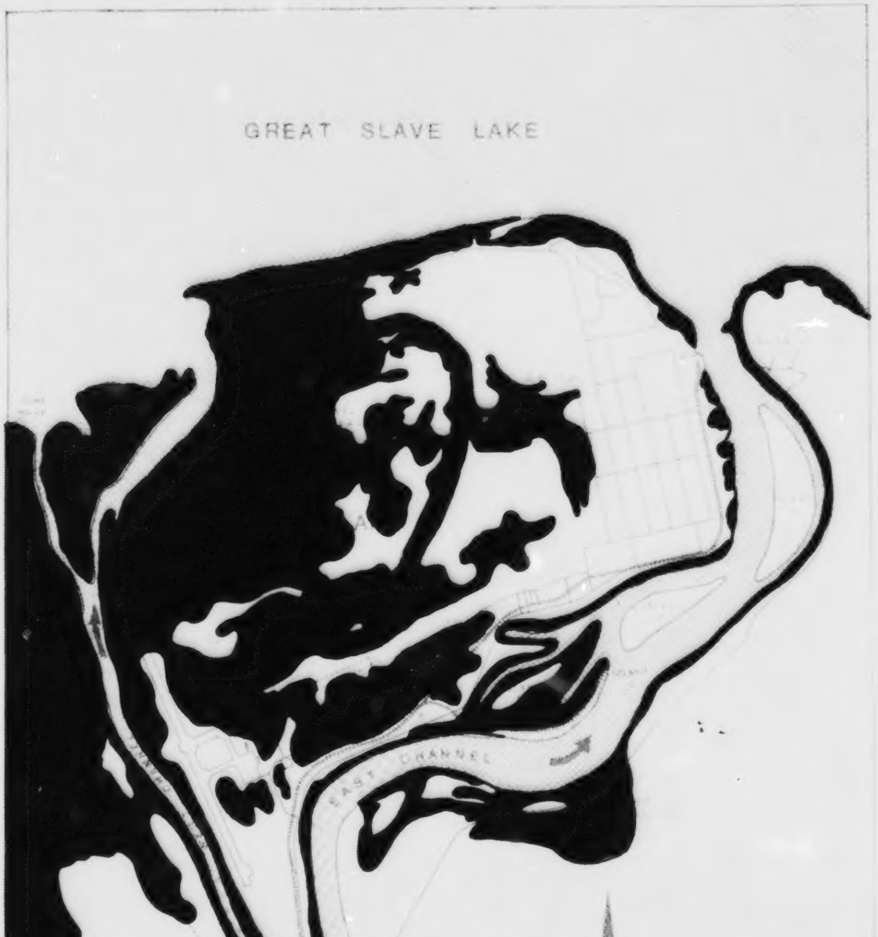

GREAT SLAVE LAKE
EAST CHANNEL
N
HAY RIVER, N.W.T.
■ - Flooded Areas,1985
HAY RIVER

Figure 6. Flooded Areas, 1985 Hay River Flood

transporting ice cakes, pans and debris.

4) The ice pressure ridge location, offshore in Great Slave Lake, contributed to jam creation where the West Channel discharges into Great Slave Lake. The ridge location also hindered long-shore movement of West Channel flood water.

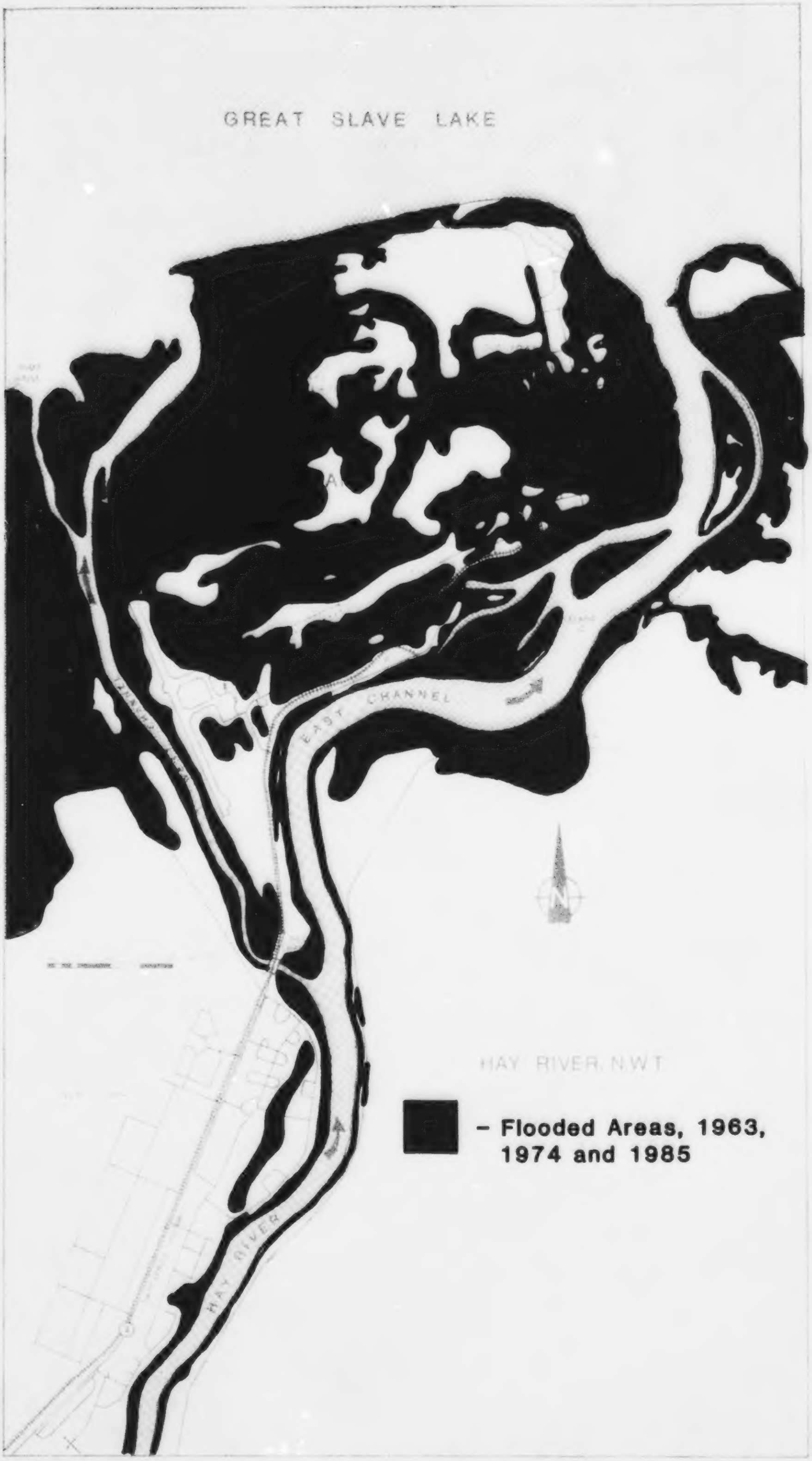

GREAT SLAVE LAKE
EAST CHANNEL
HAY RIVER
HAY RIVER, N.W.T.
■ - Flooded Areas, 1963, 1974 and 1985

Figure 7. Combination, FDR and 1985 Flood Lines

5.0 CHRONOLOGY OF THE 1985 FLOOD

5.1 The Hay River Emergency Measures Report

Sources for the following dateline summary are from the Hay River Emergency Measures Organization Summary Report, (1985) and from the detailed Flood Watch Record attached to it.

March 25:

The presence of a 4m high ice pressure ridge close inshore on Great Slave Lake was reported to Town Council by Red McBryan.

April 20:

Hay River Emergency Measures Organization (EMO) Committee conducted an aerial reconnaissance of upper Hay River Basin. Conditions on the Chinchaga led to an estimate of approximately two weeks until breakup in Hay River. It was reported that conditions appeared right for a very high runoff.

April 29:

A second reconnaissance was made.

May 01:

Flood evacuation procedures were published in the Hub, the Hay River weekly newspaper.

May 02:

Radio announcements warned residents of West Channel and Vale Island of ice movement expected at midnight.

May 03:

A flood watch was instituted at 08:00. Bankfull river conditions reported at 17:30 from Indian Cabins, just south of the Alberta border. A two metre drop at 20:30 at Paradise Gardens indicated that an initial flood wave had passed through beneath the ice cover. A state of local emergency was declared in Hay River at 21:00.

May 04:

Little change - flood watch reduced.

May 05:

Indian Cabins reported huge release prior to 07:00 but river velocities soon slowed although water levels remained high along the river.

May 06:

Rapid flow reported from Paradise Gardens at 02:30. Ice began to move in East Channel and water levels rose. The old village on Hay River Reserve was evacuated to the Community Hall in New Village or to private residences. St. Paul's school was closed at 09:40. Water levels continued to rise slowly and at

13:00 it crossed the Mackenzie Highway at the entrance to Island D and washed out the rail spur to the island. A helicopter survey at 16:00 showed ponding behind the pressure ridge at the mouth of West Channel, that Island D was underwater and that the new Indian Village was experiencing some flooding. Evacuation of West Channel residences began in the evening.

May 07:

Just after midnight, at 00:30, a huge surge of water and ice was reported moving down West Channel. Within 15 minutes roads in the West Channel were flooded to depths exceeding one metre.

Remaining residents were evacuated by truck or front-end loader. The suddenness of the event prevented siren warnings to be given in time and also prevented firefighters from responding adequately.

Ignoring his own safety, Pat Bobinsky, private citizen, rescued several people from rooftops by canoe when he realized other means of rescue were not possible. All residents were evacuated safely within 90 minutes of the flood surge. Evacuees were cleared through EMO office and accommodated in local hotels. Preparations were initiated to blast away the pressure ridge at the West Channel mouth. A special committee was established to deal with evacuee's housing needs. The state of local emergency was extended. Vale Island old town residents were advised of possible evacuation requirements.

May 08:

West Channel water levels continue to fall and flows down East Channel are below channel capacity with ice still in place. At 08:30, the Old Town flood advisory was withdrawn and St. Paul's reopening on May 09 was announced. At 20:00, there was some ice movement and water level rise in East Channel but the river stabilized below flood levels.

May 09:

A number of specially-struck committees met during the next three days to set courses of action for damage claims, resettlement and clean-up.

May 16:

A debriefing meeting of EMO officials discussed aspects of how the emergency was handled, which schemes went well and which needed improvement.

5.2 Water Survey of Canada (WSC)

The following comments are extracted from WSC field notes. Flow and water level data are compiled in tables in Appendix B. The WSC gauging station referred to is Hay River near Hay River, 07OB001. It is located above the Pine Point bridge.

April 19:

Above Pine Point bridge the river conditions were typical of late winter. Discharge was 4.4 m^3/s, up from March 06 flow measurements of 2.4 m^3/s. Ice thickness approximated 0.9 m.

April 25:

No water flowing over ice at Paradise Gardens, ice is still solid.

April 26:

Conditions at Paradise Gardens unchanged.

April 28:

At Paradise Gardens, the ice has lifted but not broken. Water level rose about 2 m in the afternoon of April 27 and a further 0.3 m today. Water flowing over ice and along edges.

April 29:

At gauging station, ice lifted and moved by 15:30.

At West Channel in Hay River, water flow over ice from bank to bank. Water depth about 0.5 m. Huge ice pans are randomly scattered, resting on bottom-fast ice.

In the East Channel, some water pools were observed, as well as some flow along the left bank.

At the Hay River pumping station, the ice pressure ridge was estimated to be 300 m offshore and approximately 2 m high.

April 30:

At the WSC station some further ice movement was noted creating a few open leads in mid-channel.

May 01:

At WSC station at 08:00, the water level had risen 0.4 m since yesterday. Water quality and sediment samples and a flow measurement were made between 17:00 and 18:00. The ice at the station cleared out at 15:30. A huge ice jam began about 500 m downstream. The Pine Point bridge area was also jammed solid.

May 02:

A flow measurement was made at the WSC station between 08:25 and 09:25, just before a major ice run.

At West Channel near Great Slave Lake water was observed running over bottomfast ice in channel and ponding behind the ice pressure ridge approximately 400 m offshore. Water levels in the channel are sufficiently high to encroach into trees along the bank.

At the WSC gauge at 14:00, the head of the downstream ice jam has now reached the station. Ice action has damaged the water level instrument line into the river. River level has risen 0.7 m since morning visit.

May 03:

The WSC station was clear of ice at 07:30. Between 07:30 and 09:15, there was probably a downstream ice jam release because the water level at the station fell by 0.8 m during the two hours. Over the next hour, the water levels recovered slightly and then stabilized.

May 04:

A continuous ice jam was in place at the WSC station. At 09:50, the water level stood at 8.6 m, 1.5 m higher than in the morning of May 03. On Great Slave Lake, water was evident on both sides of the pressure ridge at 10:25, this observation in the vicinity of the pumphouse. The East Channel in lower reaches is now about 25% open along the left bank. The West Channel is jammed solid from the lake up to and beyond the West Channel bridge. Above the bridge, the river is jammed upstream all the way to Paradise Gardens. Great Slave Lake levels remain constant at elevation 1.7 m.

May 05:

At 11:55, little change over last 24 hours at WSC station.

May 06:

In the East Channel at 07:00, the ice has jammed half way between the bridge and the lake. Ice push even with top of the road in the vicinity of the airport. At WSC station at 09:15, the ice had moved out. The river was flowing ice and debris on right half of river. Ice piled on both banks. At 12:05 the river was still running ice and the water level was falling at the rate of 0.1 m every 5 minutes. From the chart record, the peak water level to date occurred at 11:00 at a level of approximately 9.5 m. Between 14:40 and 18:30 the water levels again rose, from 8.489 m to 9.440 m. A flow measurement was made on West Channel from the traffic bridge between 20:40 and 21:55 - 468 m^3/s. Approximately three metres of ice pile-up was noted along West Channel river banks.

May 07:

Flow measurement at WSC station between 11:15 and 12:35 at water level of 6.883 m. High velocities, the mean was 1.7 metres per second. Another measurement of the West Channel at the traffic bridge was made between 15:30 and 17:15 - the discharge was 470 m^3/s, unchanged from the measurement of the evening of May 06.

May 08:

A measurement at WSC station between 09:00 and 10:20 showed that the ice and associated backwater effects were gone and also, that the river channel had scoured during the breakup.

5.3 Discussion

The previous two sections provide between them a comprehensive chronology of the 1985 spring flood in Hay River. Two quite different perspectives of the event are presented; the first from the viewpoint of local citizens dealing with a major catastrophe and the second from an engineering or technical water resource view. The two chronologies complement each other to provide a more complete picture of the sequence of flood events from May 3-8 than either would by itself.

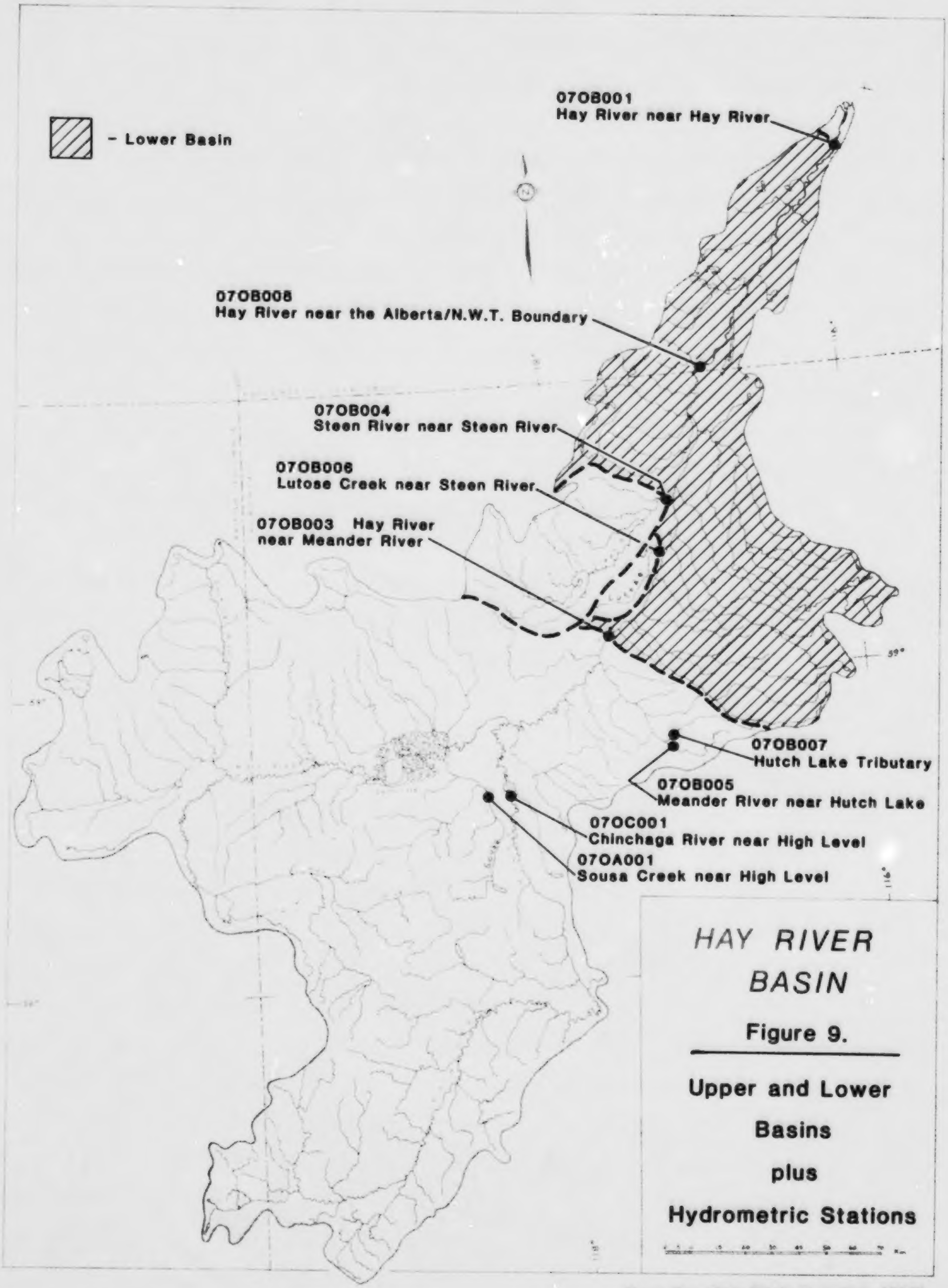
Hay River EMO office also kept a detailed radio log which included records of water levels at selected stations throughout the emergency. The most complete record of water levels was obtained at the West Channel traffic bridge to Vale Island. Although many of the readings are relative ones, i.e., "six inches lower than the last reading ", it has been possible to reconstruct the approximate water levels at the West Channel traffic bridge in a graph, Figure 8 (contained in back cover pocket), and to compare it to the WSC data obtained at their station. It can also be seen that the two records compare favourably and that there was a significant time interval between the release of the ice jam in the vicinity of the WSC station and the main flood wave passage down West Channel in the early hours of May 07.

6.0 DISCUSSION AND ANALYSIS

Exceptionally high flows were one of the three factors which contributed to the 1985 spring flood in Hay River. Flow records obtained from Water Survey of Canada (WSC) 1985 data books show that the source of extremely high flows is a bit of a mystery. Figure 9 shows where WSC stations are located within the Hay River Basin. The four lower stations, Hay River near Meander River, Lutose Creek near Steen River, Steen River near Steen River and Hay River near Hay River are of interest for this analysis.

The flows listed in Table 1, page 26, for the station, Hay River near Hay River, 07OB001, represent the discharge from the entire upstream basin. The area upstream of this station is 47 900 km^2; total basin area above Vale Island on Great Slave Lake is 48 100 km^2. The gauged area above 07OB001 thus represents 99.6% of the total basin area.

The station on Hay River near Meander River, 07OB003, records the river flow from the entire river basin above it, an area of 36 900 km^2 or 76.7% of the total. Lutose Creek drainage area is 292 km^2; 0.6% of the total basin and Steen River catchment area is 2 610 km^2 which is 5.4% of the Hay River Basin. Together, these three sub-basins total 39 802 km^2, 82.7% of the total. By simple subtraction, the area below these three sub-basins but above the downstream station at Hay River is 8 100 km2. This area is 16.8% of the basin. On Figure 9, it is the shaded portion of the Hay River drainage, identified on the map as the Lower Basin.


▨ - Lower Basin
07OB001
Hay River near Hay River
07OB008
Hay River near the Alberta/N.W.T. Boundary
07OB004
Steen River near Steen River
07OB006
Lutose Creek near Steen River
07OB003 Hay River
near Meander River
07OB007
Hutch Lake Tributary
07OB005
Meander River near Hutch Lake
07OC001
Chinchaga River near High Level
07OA001
Sousa Creek near High Level
59°
116°

HAY RIVER
BASIN

Figure 9.

Upper and Lower
Basins
plus
Hydrometric Stations

(from Hay River Basin Overview, 1984)

Date		07OB001 Hay River near Hay River (m3/s)	07OB003 Hay River near Meander River (m3/s)	07OB006 Lutose Cr. near Steen River (m3/s)	07OB004 Steen River near Steen River (m3/s)	Total Discharge in Lower Basin (m3/s)	Lower Basin Yield (mm)
April	27	182	137	1.08	10.3	33.6	0.36
"	28	229	185	2.40	11.2	30.4	0.32
"	29	306	252	3.27	13.7	37.0	0.40
"	30	313	244	3.90	17.9	47.2	0.50
May	1	387	267	4.53	27.8	87.7	0.94
"	2	542	269	4.49	40.2	228	2.43
"	3	511	280	3.69	44.4	183	1.95
"	4	861	370	4.72	46.1	440	4.69
"	5	1 000	405	8.70	49.4	537	5.73
"	6	1 350	418	11.0	49.6	871	9.29
"	7	1 310	431	9.33	52.6	817	8.72
"	8	1 230	447	8.83	62.5	712	7.60
"	9	1 200	478	8.04	64.4	650	6.93
"	10	1 200	496	6.91	66.1	631	6.73
"	11	1 200	482	7.27	66.3	644	6.87
"	12	1 180	450	7.03	64.0	659	7.03
"	13	1 150	417	6.58	60.5	666	7.10
"	14	1 100	388	6.08	57.5	648	6.91
"	15	1 010	362	5.60	54.0	588	6.27
"	16	914	338	5.21	50.5	520	5.55
"	17	827	315	4.82	46.5	461	4.92
"	18	752	297	4.43	42.0	409	4.36
"	19	691	280	4.10	38.0	369	3.94
"	20	634	267	3.75	34.5	329	3.51
"	21	581	256	3.41	30.5	291	3.10
"	22	537	247	3.06	27.0	260	2.77
"	23	500	241	2.69	24.5	232	2.48
"	24	466	234	2.23	21.0	209	2.23
"	25	439	227	1.81	18.5	192	2.05
"	26	413	224	1.48	16.0	172	1.84
"	27	392	220	1.20	14.0	157	1.68
"	28	375	216	0.975	12.0	146	1.56
"	29	362	214	0.810	10.3	137	1.46
"	30	348	211	0.753	9.89	126	1.34
"	31	338	210	0.823	9.73	117	1.25
June	1	331	207	0.898	9.93	113	1.21
"	2	327	204	0.920	9.70	112	1.20
"	3	322	200	0.912	8.92	112	1.20
"	4	316	197	0.875	8.20	110	1.17
"	5	306	195	0.938	7.69	102	1.09
"	6	297	193	0.882	7.31	95.8	1.02
"	7	290	191	0.980	7.04	91.0	0.97
"	8	284	189	0.956	6.82	87.2	0.93
"	9	286	183	0.997	6.53	95.5	1.02
"	10	283	180	1.01	6.25	95.7	1.02
"	11	276	176	0.996	6.05	93.0	0.99
"	12	273	172	0.920	5.83	94.3	1.01
"	13	266	170	0.908	5.60	89.5	0.96
"	14	257	167	0.962	5.42	83.6	0.89
"	15	251	165	0.957	5.19	79.9	0.85
"	16	246	163	1.02	5.50	76.5	0.82
"	17	243	163	1.14	5.80	73.1	0.78
"	18	244	162	1.24	6.06	74.7	0.80
"	19	245	158	1.24	5.79	80.0	0.85
"	20	239	154	1.19	5.59	78.2	0.83
"	21	233	152	1.10	5.47	74.4	0.79
"	22	231	148	1.02	5.41	76.6	0.82
"	23	226	145	0.923	5.01	75.1	0.80
"	24	220	143	0.855	4.28	71.9	0.77
"	25	214	141	0.803	3.80	68.4	0.73
"	26	208	139	0.814	3.59	64.6	0.69
"	27	203	137	0.843	3.39	61.8	0.66
"	28	200	138	0.780	3.29	57.9	0.62
"	29	196	137	0.680	3.15	55.2	0.59
"	30	192	135	0.598	3.01	53.4	0.57

Table 1. Daily Discharges and Yield, Lower Hay River Basin, April 27 - June 30, 1985

If the sum of the daily flows from the three upstream stations is subtracted from the daily flows at the downstream station, then this difference should represent the daily flow values generated in the Lower Hay Basin. If this is done day for day, the differences will only be approximately correct, since it assumes zero travel time from the upstream stations to the lower one. Over the extended period of the 1985 spring breakup, these slight day-to-day errors are compensating and therefore not considered here, although they will be of interest in a later section which examines flood-warning.

As illustrated in Figure 10, a startling picture of flow distribution in May and June of 1985 emerges from this analysis. For a period of 14 days the 16.8% land area of the Lower Hay Basin produced more than half the total discharge recorded near Hay River. Review of WSC field programs at the lower Hay River station showed that excellent coverage was obtained and that the data are fundamentally correct. Survey records are summarized in Appendix B.

It is not easy to compare the runoff from differently sized basins by use of published WSC data because flow rates in cubic metres per second from basins or sub-basins of different size generate vastly different discharges even when the runoff per square kilometre might be quite similar. A better way to compare surface runoff is to convert the published data, in cubic metres per second, into millimetres of runoff per day. An additional benefit from this conversion is that the converted units are the same as those used by Atmospheric Environment Service (AES) for precipitation data.

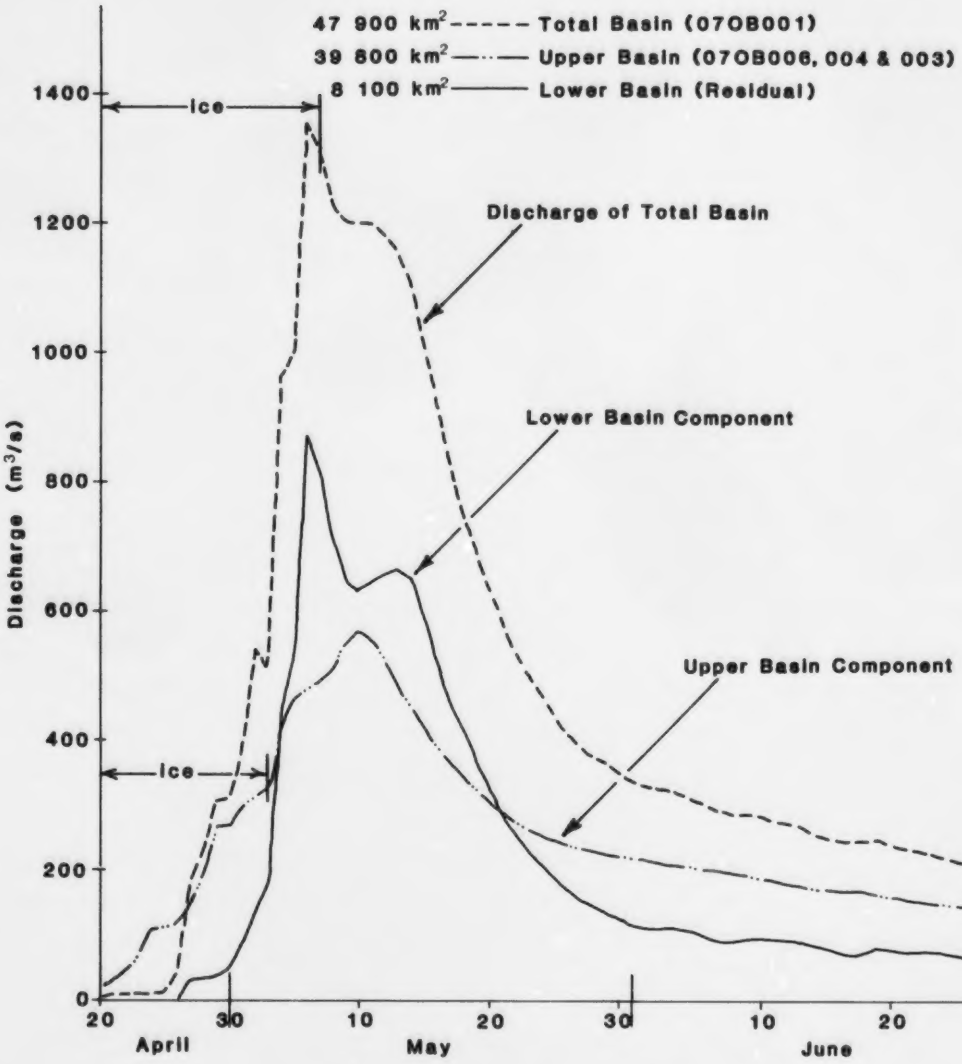


Figure 10. 1985 Spring Flood Discharges

Meaningful comparisons can thus be made between WSC and AES data. Table 1 lists the WSC data as published and the converted data for the same period, late April to end of June, and Figure 11 shows the converted data for the basin. The shaded portion under the line graph in Figure 11 represents the snowmelt runoff from the Lower Basin in

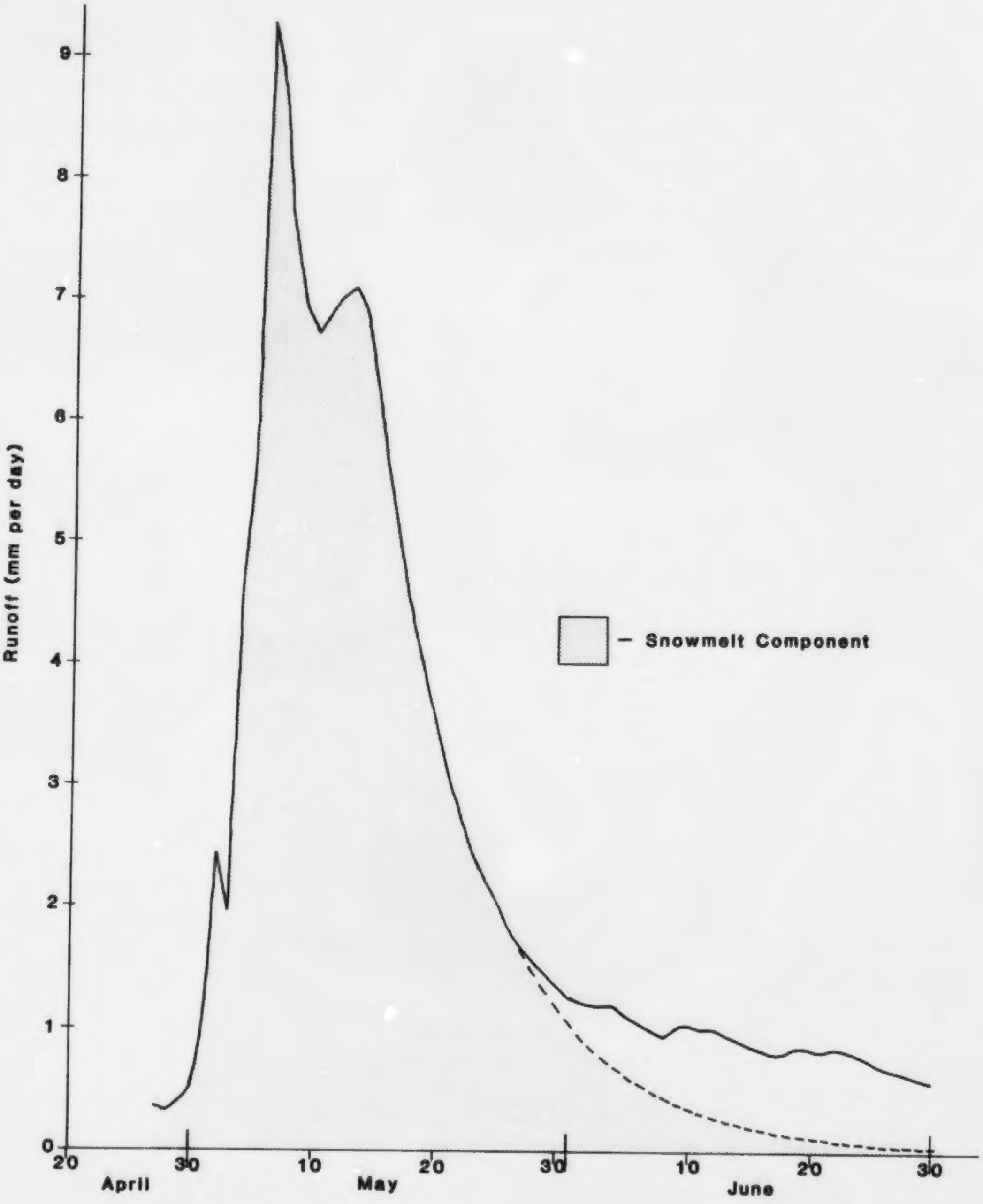


Figure 11. Runoff Components, Hay River, Spring, 1985

millimetres for the period, April 27 to June 30. The sum of the daily values for this period in Table 1 is 161 mm. This total can be broken down into several components, best illustrated graphically. Figure 12 shows this breakdown of the spring runoff into that part attributed to snowmelt and rainfall during the melt, and into that part which derives from groundwater and/or post-melt rainfall.

River channels within a catchment, when filled with water from snowmelt or from rainfall, behave in a similar fashion hydraulically, as a storage tank with a bottom drain. Rate of flow is greatest when the tank is full and the rate reaches zero when the tank or the river catchment is empty. The rate of change of this flow varies mathematically so that each successive time unit's flow rate is a fixed fraction of the flow rate in the time unit just preceding. If the snowmelt and rainfall in late April-early May, 1985 is lumped as a single-source of water input into the Hay River, then as Figure 12 indicates, the hydraulic rate of change in flow in the Lower Basin is such that each succeeding day's flow is 0.894 of the preceding daily discharge. When this regression constant is applied to the spring flood and extended down to near zero with a straight line, it becomes possible to separate the spring flood waters from those derived from later inputs from summer rains or from ground water. Regression constants for these later events at lower flows show a regular departure from the snowmelt value of 0.894 as illustrated in Figure 12. The estimate of spring flood water is represented by the hatched area and it represents 143 mm of average runoff over the area in the Lower Basin. This value can now be compared to precipitation inputs into the Lower Basin in the form of snow and rain.

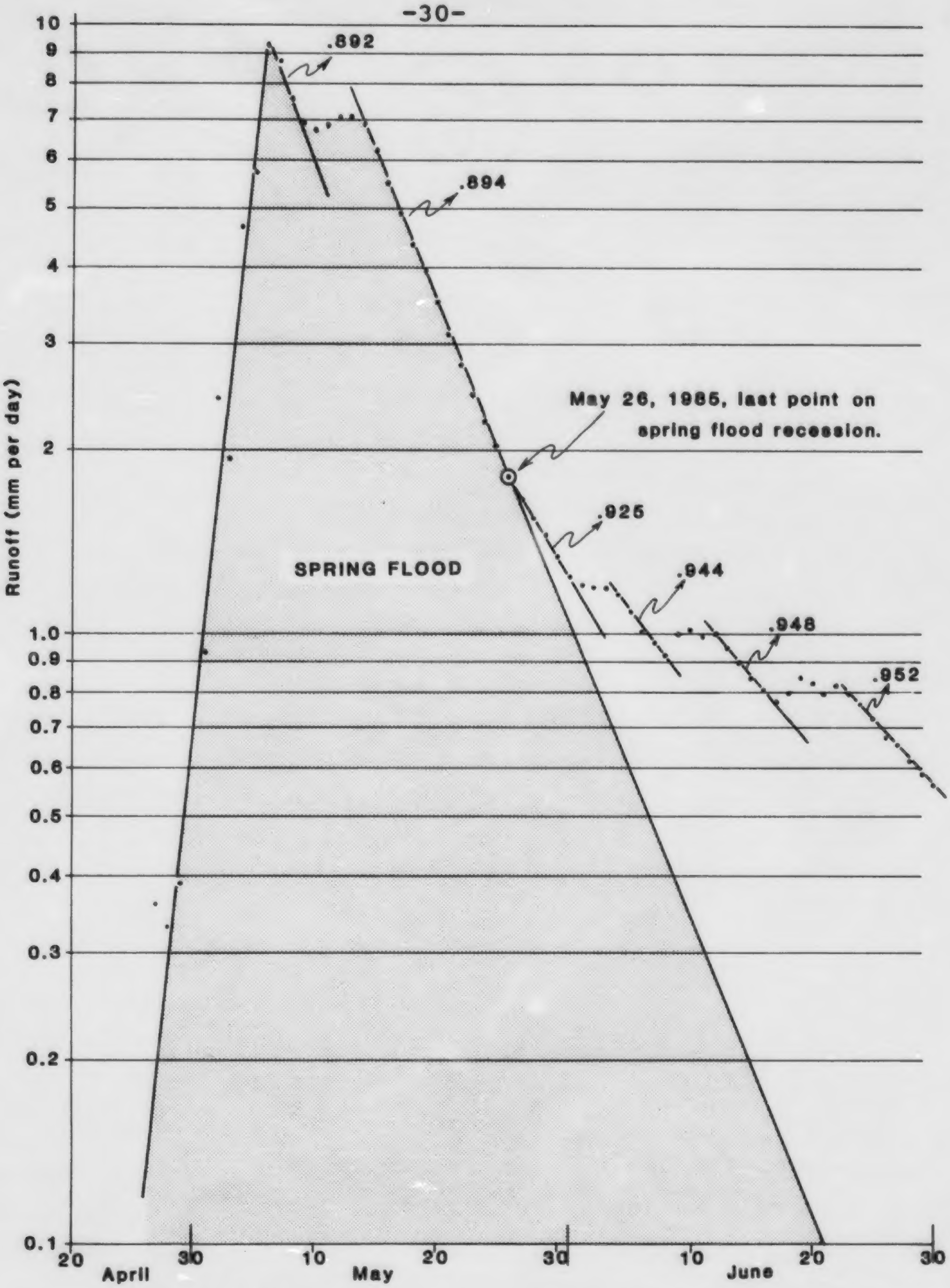


Figure 12. Runoff, Log Plot, Hay River, Spring, 1985

For precipitation, the snow accumulation period in the previous winter and the rain before May 13 are considered to be inputs.

According to Drews (1986), Appendix C of this report, freeze-up and therefore snow accumulations in the autumn of 1984 began approximately October 21, 1984. Total precipitation at Hay River Airport for October, obtained from Table 1 of his report, was 81.5 mm of which approximately 50 mm fell as snow. Net accumulation of snow October 31, was 12 cm. Some melt and collapse of October snowfall is apparent. An estimate of 30 mm of net snow-water equivalent accumulation is used in Table 2.

Date	mm. of Precip.	Runoff (Lower Basin)
October 84	30	
November 84	20	
December 84	17	
January 85	15	
February 85	26	
March 85	4	
April 85	20	
May 3-13 85	25-30*	
Totals	159 mm	143 mm (90% of Precip.)

* estimated by Drews (1986, p. 6)

Table 2: Winter Snow and Spring Rain Accumulations at Hay River Airport - 1984-85

There are several difficulties with direct comparison of the totals in Table 2. The precipitation data is relevant only to the weather station at Hay River Airport and the runoff in the Lower Basin represents an average value over 8 100 km^2 of land surface. It is likely that much more snow and spring rain was available from the high ground in the Caribou Mountains than was available at Hay River Airport. It is normal for surface runoff to represent 20 to 40% of the total precipitation during spring runoff in northern boreal forest regions. The departure from this ratio in Table 2 points out the need for a more dense network of climate stations.

6.1 Future Flood Probabilities

By way of introduction to this most complex topic, consider that floods are discrete, unconnected events, much in the same way as separate coin tosses are unconnected. If one were to toss a coin 20 times, the expected result would be 10 heads and 10 tails. The chances of 20 heads in 20 tosses are very remote; a result like this might happen once every 1000 trials. Most of the time, the expected result would be somewhere close to 10 heads and 10 tails; something like 7 heads and 13 tails or 8 tails and 12 heads. It is possible to assign values to the chances of a flood of a certain size in a related fashion.

For the Hay River station near Hay River, the sample size of annual floods is 23, collected in the period 1964 to 1986, inclusive. This is only a small fraction of the total number of floods which have happened since the last ice age. To increase the size of the available sample, Underwood McLellan (1978) estimated annual floods for the period, 1936 to 1963, from the Hay River record of precipitation. These estimated or synthetic annual floods, when added to the measured floods of later years, increases the sample size of annual spring floods to 51. Mathematical analysis of this larger sample by two different techniques produces two quite different results:

a) The first result, based on Normal or Gumbel distribution, says that the 1985 flood of 1 350 cubic metres per second has one chance out of 230 of happening in any given year.

b) The second result from analysis of the same data, using the 3-parameter Log-Normal distribution, says that the 1985 flood has one chance out of 42 of happening in any given year.

In a non-mathematical sense, the 1985 flood happened once in the last 23 years and two other floods of similar destructive capability happened in 1963 and in 1974. Further, it should be noted that the three significant floods were eleven years apart.

It has been said before that destructive floods in Hay River have other causes than just sheer volume of flow. Analysis of historical events suggest that the timing of high flows to coincide with river ice breakup is equally important. A third factor which must be considered on Vale Island is the location and size of the ice-pressure ridge offshore in Great Slave Lake. Based on these other concerns the simple analogy to a coin toss probably no longer holds true, since the situation is so much more complex. The probability question becomes a three-part one with the following constituents:

> What is the probability of an ice pressure ridge forming on the Great Slave Lake

shoreline, of sufficient size and in a location which prevents water from escaping onto the ice of Great Slave Lake at the same time as a major streamflow event in the period of river ice breakup?

Said another way, the combination of the chances of three things happening together is what must be calculated; the combined probabilities of a significant streamflow event, the occurrence of that event during the ice period, and the formation of a large ice ridge in a critical location. The result could then be used to estimate the chances of a destructive flood in Hay River. These three factors combined to create the 1985 flood in Hay River. Some information is available for the first two elements but little information exists for the third; the size and location of ice pressure ridges.

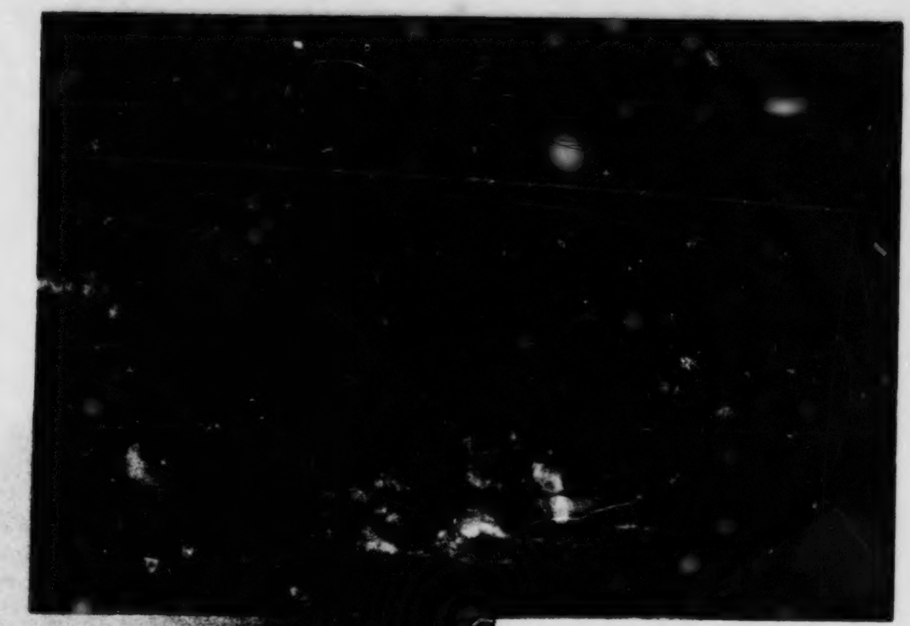
6.2 Ice Pressure Ridges

The physical principles which explain the formation of pressure ridges on large northern lakes are generally understood. Ice, like any solid, expands when warmed and contracts when cooled. An ice sheet of sufficient thickness, so that the upper portion is more affected by air temperature rather than by the water underneath, will contract in cold periods and expand in milder spells of a typical northern winter. A prolonged cold spell will cause the ice sheet to shrink and crack along lines of weakness such as the zone where the shorefast ice joins the floating ice sheet. The open water exposed in such a crack will freeze quickly in a cold spell. Subsequent warming will cause the ice sheet to expand and buckle the ice along the same fault lines. The size of the ice pressure ridge therefore depends upon the number of cold-warm cycles in the ice season.

At Hay River the zone of weakness where shorefast ice meets floating ice is variable from one year to the next. It is speculated that year-to-year variation in ice ridge location is linked to variations in the near-shore lake bottom configurations. Since bottom materials in the near-shore are sand, the shape of the lakebed outwards from the shore depends upon wave action - wave action from the most recent storms before or during the freezeup in the fall. A large storm blowing onshore will generate very large waves which will tend to remove sand from the beach and move it further offshore where the sand is deposited as sandbars. Smaller waves tend to move sand inwards, onto the beach. Such variations in the near-shore bottom configurations will determine where shore-fast ice meets the floating ice sheet and, hence, where the annual ice pressure ridge will form. Lake levels will, of course, also influence just where the shore ice-floating ice boundary is located. Very little research has been done on the combination of these two physical principles, which is why this process remains speculation.

At Hay River in May, 1985 the pressure ridge was fairly close inshore and of sufficient size to hinder the escape of ice, debris and very large water discharges onto the floating ice sheet beyond the pressure ridge, Figure 13. A satellite image made on May 6, 1985, showed that the pressure ridge

Pressure Ridge on
Great Slave Lake
off West Channel,
April 29, 1985



Water ponding behind
the pressure ridge
(arrow) as seen from
the pumping station,
May 5, 1985

Breakthrough point in
the pressure ridge
(arrow) and debris
outwash fan over lake
ice off West Channel,
morning, May 7, 1985

Figure 13. Details of the Pressure Ridge, Hay River, 1985
(WSC photos)

was breached before the very high water of the night of May 7, but the rupture wasn't sufficient to allow the very high discharge to escape. The last photograph in Figure 13 shows the results of the impoundment release as it appeared on the morning of May 7.

Underhill Engineering Ltd. of Hay River was hired to survey high water marks in the affected areas of Hay River in the post-flooding period. Their data for the Fishing Village, shows that flood waters reached elevations of 2.4 m above lake levels at a location where one would expect water levels to dissipate over the lake ice. The location of the ice pressure ridge would appear to be a direct cause. It would also play a secondary role by holding back the initial pan ice and debris which would subsequently become grounded as water dissipated along the nearshore of Great Slave Lake. Together, these features gave rise to the very high flood levels recorded in the Fishing Village.

6.3 River Ice Jams and Water Levels

River ice jams in the lower Hay River and in the East and West Channels are at least as important as high river flows to the floods in Hay River. In 1985, there are two sources of information on the impact of ice jams on flood levels:

1) Recorded water level data from the Water Survey of Canada station, 070B001, three kilometres upstream from the bridge on Pine Point Highway #5 or 13 km above the West Channel bridge in Hay River.

2) The radio log kept by the Hay River Flood Emergency Committee for the period, May 3 to May 8, 1985.

Comparison of the two in the earlier Figure 8 suggests that the major Pine Point bridge ice jam release beginning at 23:00 on May 6 caused the maximum flood level at West Channel Bridge four hours later. In a similar manner, the 11:00 release on May 3, at Pine Point bridge is reflected by increased water levels in Hay River about four or five hours later. Finally, the first major break in the ice jam at the WSC station which destroyed the gauge sensor tubing at 23:00 on May 5, is reflected in a sharp rise in Vale Island water levels at 03:00 on May 6. In summary, increased water levels downstream at Hay River appeared to be reactions to ice jam releases at Pine Point Highway bridge three to four hours earlier. This may not hold true for floods of other years, but the 1985 flood peaks at Vale Island could have been forecast by three or four hours from information at the WSC station above the Pine Point bridge.

6.4 Calculation of Flow

WSC technicians routinely measure streamflow and water levels at selected river stations across Canada. This is done in order to produce a record of daily flows which are published annually.

In open-water conditions, water level and streamflow are related to each other by a curve of relationship as shown in Figure 14. Periodic measurements as

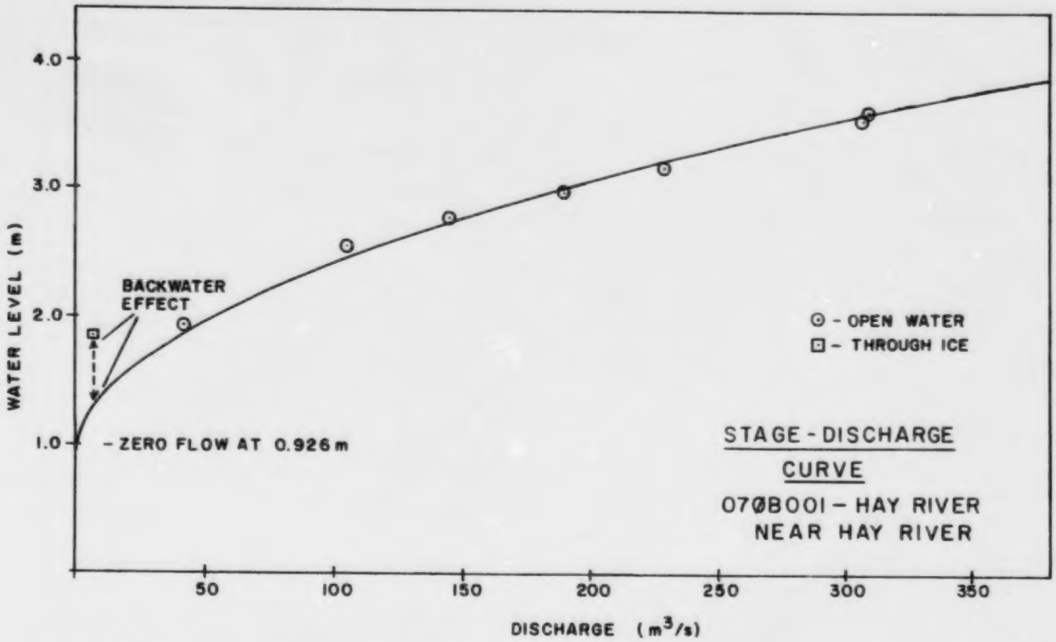


Figure 14. Stage-Discharge Curve and Backwater Effect

illustrated in Figure 15, are made to define the curve of relation for the range of flow in a given year. Once ice forms on the river, the relationship no longer holds true; the water levels for a given flow are greater because of increased friction from the ice cover. Shifts away from the curve are determined from measurements through stable ice cover as illustrated in Figure 16.

Once the ice breaks and jams, neither of these two methods to measure the flow is possible. This was the case at the WSC station on Hay River above the Pine Point bridge from 12:00 on May 3, 1985 to 12:00 on May 7. Streamflow for such periods must of necessity be estimated by dividing the water level record into two constituents - that part which is

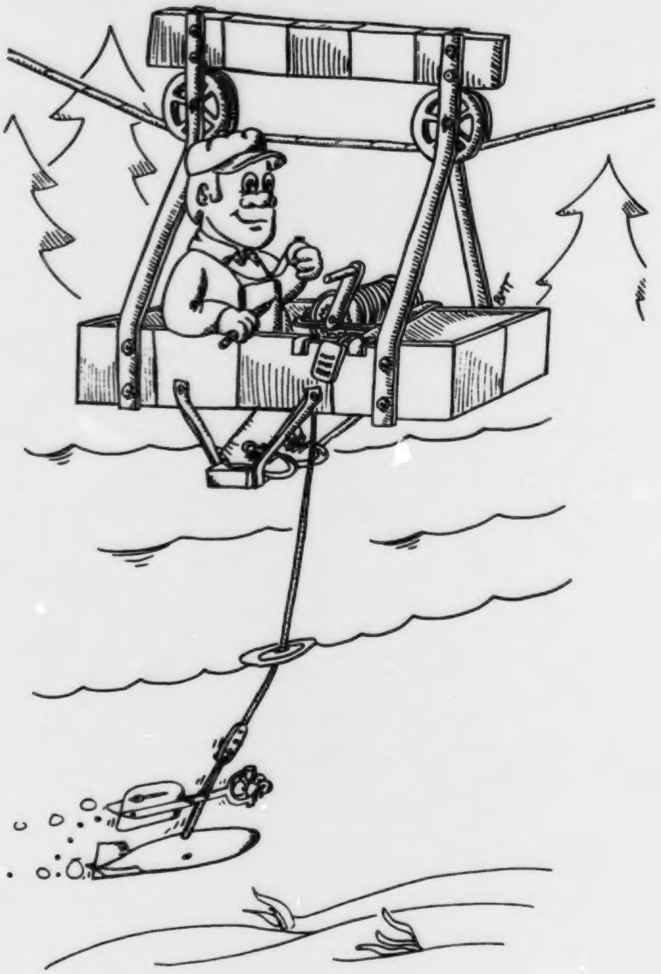


Figure 15. Open Water Streamflow Measurement
(B. Thorson)

created by the damming effect of the ice, also called backwater, and that part which is caused by the high streamflow. Such estimates are generally made on a daily basis and the data are listed as daily mean flow. In Figure 8, the water levels corresponding to these estimated flows are plotted

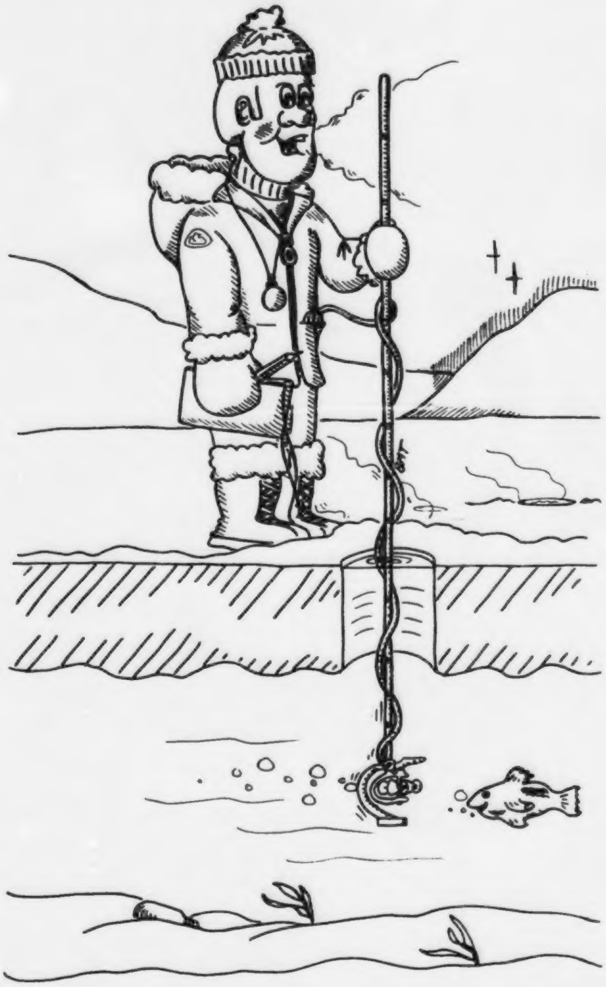


Figure 16. Streamflow Measurement Under Ice
(B. Thorson)

with an 'x' for May 4, 5 and 6. The dotted line for May 6 is a suggestion of how the streamflow varied about the published estimate for that day. The suggested line takes into account ice-jam buildups and releases. During release, the flows increase sharply because the ponded water in the river channel upstream is discharged; during ice-jam buildup, water is stored in the upstream pond and flow past the station is decreased. It is of note that the estimates for May 6 were made before comparison to the Vale Island data and that the dotted line shows reasonably good agreement with the water level record three hours later in Hay River. The other estimate of interest is the one for instantaneous peak flow at midnight on May 6, 1985 of 1 770 m^3/s. Finally, the estimated increase in water level at the WSC Hay River station, 07OB001, because of ice effect was greater than 3 m for May 4 and 5. The backwater effect has been shaded in Figure 8.

6.5 Analysis of the Historic Flood Record

The published, annual daily-mean flood record, Table 3, shows WSC data records from 1964 to 1986, or 23 years. Of these, two were estimated because of water level instrument malfunction, eleven occurred when ice affected the stage-discharge relation and three were the result of early-summer rainstorms in June or July when river flows were still high from the spring melt. For these last three years, the annual flood later in the summer is greater than the spring breakup flood. The snowmelt floods for these years were as follows:

1977 - 530 m^3/s on April 27
1979 - 694 m^3/s on April 22
1984 - 172 m^3/s on April 21

A review of the history of flooding in Hay River shows that catastrophic floods took place in 1963,

Year	Maximum Daily Discharge (m^3/s)	Maximum Instantaneous Discharge (m^3/s)
1964	725 on May 8	---
1965	708 on May 1	---
1966	521 on May 15	---
1967	957 on May 11	1 020 at 2030 MST on May 10
1968	518 on May 6	524 at 1800 MST on May 6
1969	889 on May 7	---
1970	374 on May 3	---
1971	600 on May 1	---
1972	1 020 on May 9	---
1973	595 on Apr 29	---
1974	1 180 on May 3	---
1975	680 on Apr 30	---
1976	685 on Apr 30	---
1977	1 080 on Jun 14	1 080 at 1645 MST on Jun 15
1978	818 on May 3	---
1979	1 120 on Jun 5	---
1980	120 on Apr 28	---
1981	790 on May 4	---
1982	657 on May 9	---
1983	550 on Apr 30	---
1984	617 on Jul 9	621 at 1756 MST on Jul 8
1985	1 350 on May 6	---
1986	900 on May 6	1 440 at 2044 MST on May 6

Table 3. Maximum Discharges at WSC Stn. 07OB001, Hay River near Hay River

1974 and in 1985. In all of them large snowmelt floods combined with ice to produce disasters in the town. For these years the flow data are as follows:

1963 - 899 m^3/s (estimated - no date)
1974 - 1 180 m^3/s on May 3
1985 - 1 350 m^3/s on May 6

Floods in other years were of similar size, but they did not create havoc in Hay River because they occurred after the ice was gone.

A significant hydrological record has been compiled by Grade 8 social studies students of Diamond Jenness Secondary School in Hay River (Diamond Jenness School, 1978). The record, extracted from historical documents, identifies the day when East Channel around Vale Island was clear of ice. With four exceptions, the record is complete from 1894 to 1977. WSC records for clear of ice conditions at their station near Hay River were used to update this water resource time series to 1986 after comparing the period of common record from 1964 to 1977. The comparison is shown in Table 4.

Year	Diamond Jenness Study	WSC	Flow at Ice Out (m^3/s)
1964	May 10	May 10	637
1965	May 04	May 04	708
1966	May 12	May 14	476
1967*	May 13	May 06	61
1968	May 04	May 03	439
1969	April 29	April 29	796
1970	May 07	May 07	357
1971	April 30	April 30	501
1972	May 10	May 10	1 010
1973*	May 02	April 24	8
1974*	May 04	April 29	626
1975	May 01	May 01	634
1976	April 27	April 26	665
1977	May 04	May 03	334

* Significant Disagreement

Table 4: Ice Out Comparison, Diamond Jenness Study vs. WSC Data

Disagreement between the two records is noted in 1967, 1973 and in 1974. In the first two cases this disagreement is probably linked to the low volumes of flow in Hay River at the time of breakup, i.e., these were likely thermal breakups where most of the ice melted in place. In general, agreement between the two records was sufficiently good to treat them as one continuous data set.

Statistical analysis was done for this array of dates after they were converted to Julian days, i.e., day number from January 1. This produced the results shown in Table 5.

```
Number of Observations =     89
Maximum                =    143
Minimum                =    112
Sum of Observations    =  11263
Mean                   =    126.551
Variance               =     44.6366
Standard Deviation     =      6.68106
Coef. of Variation     =      0.527936E-01
Skewness               =      0.134574
Kurtosis               =      2.80283
95% confidence interval on the Mean
Lower Limit            =    125.143
Upper Limit            =    127.958
```

Table 5: Univariate Analysis of Ice Out Record,
Hay River, N.W.T., 1894-1986

It can be observed from the results for skewness and kurtosis in Table 5 that the distribution approximates a normal or bell-shaped distribution, i.e.

	Actual	Normal Dist.
a) Skewness	0.13	0.0
b) Kurtosis	2.8	3.0

A frequency histogram, Figure 17, illustrates the distribution. The four missing years of record were ignored in this initial analysis. A slight refinement in the statistical analysis would derive from estimates for the missing four years; estimates which would use the mean day of 126.5 on the Julian Calendar.

Figure 18 shows an analysis of variance where the deviation of each year's ice-free date is plotted and compared to the mean. There does not appear to be any apparent trend from earlier to later breakups or vice versa, although there appears to be less scatter about the mean in the period, 1920 to 1975 than there is in the first 30 or the last 10 years of the record.

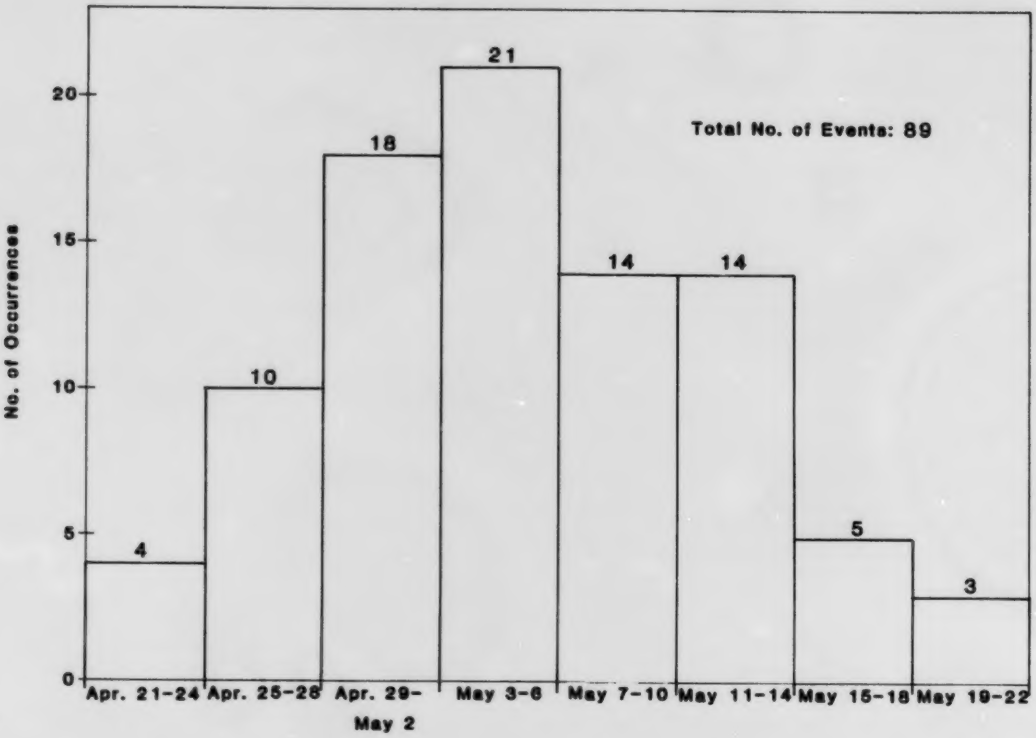


Figure 17. Histogram, Dates of Ice Out on East Channel of Hay River, 1894-1986

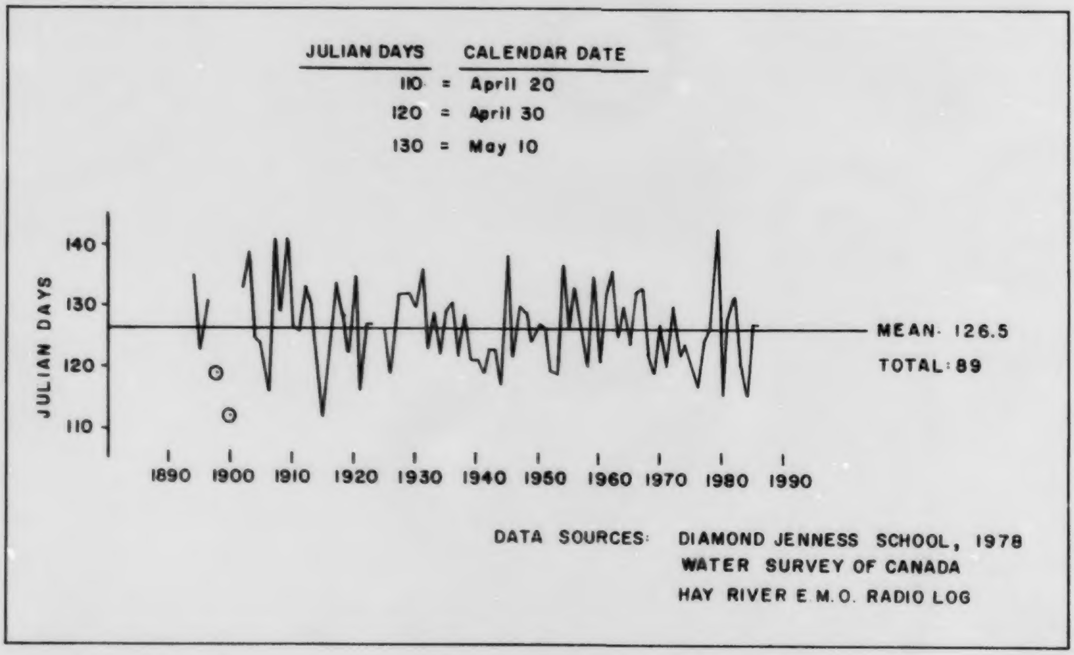


Figure 18. Variance of Ice Out Dates in East Channel, Hay River

7.0 FLOOD FORECASTING

Reliable, early warning for impending floods in settled areas is economically significant and averts casualties. Easiest to forecast are rainfall floods in large rivers. In ice-free conditions such events are easy to simulate with mathematical models and downstream events can be predicted with some certainty days or even weeks in advance.

In the case of Hay River, however, high flows are only one of the significant contributors to spring break-up floods. Of equal or greater significance are high water levels created by ice jams. Such events stem from a complex set of interactions between a number of inputs - factors such as ice thickness and degree of thermal degradation before the onset of flow, as well as the flood flow volume itself.

In the town of Hay River a number of other hydraulic conditions relate to channel size or competence, to strength of ice sheets in reaches of the East Channel and finally, to the location and size of the offshore ice pressure ridge. All influence flood magnitude and the precise area of local flooding. These local factors vary from year to year - witness the striking difference between the floods of 1963 and 1985. A safe course of action would of course be to remove everything of value from all potential flood-prone areas. Given the uncertainties attached at present to the prediction of ice-jam floods in Vale Island it would appear prudent to prepare both Old Town on East Channel and West Channel communities for flooding when predictable flood creating conditions exist.

If the river ice in East Channel between Island D and Great Slave Lake had been a little weaker or if a large jam on West Channel at the traffic bridge had partially closed the channel, it would have been Old Town which would have been inundated just after midnight on the night of May 6.

Since 1985, WSC of Environment Canada in cooperation with Water Resources Division of Indian and Northern Affairs Canada have upgraded the stream-gauging network by adding an automated recording gauge at the NWT border. This new station, Hay River near Alberta/NWT Boundary, 07OB008, is equipped with satellite retransmission facilities which can be set up to transmit water level data every hour or oftener. The WSC station above the Pine Point bridge, 07OB001, has been upgraded with a telephone link to provide water level information as required for the price of a phone call.

These facilities should provide some measure of short-term forecasting, i.e., forecasts predicting high water levels hours in advance of the actual event. Longer-term predictions will need to rely on events recorded further upstream in the Hay River basin at WSC stations in Alberta. Judicious use of these remote data could provide warning to Hay River days in advance of the event for those years where the flood originates in the headwaters. However, knowledge of these upstream flow and level conditions would not have been of assistance in the prediction of the 1985 flood event when most of the flood water appears to have originated in the Caribou Mountains.

Even earlier indicators of flooding potential could be derived from assessment of climatic conditions during the previous fall and winter. However, as the analysis by Drews (1986) shows, there is little in the AES data from their Alberta stations to provide a warning, since the Caribou Mountain autumn rainfall and late winter snow conditions were not monitored. Since 1985, DIAND have agreed to conduct snow surveys in the Caribou Mountains in the late winter of each year to provide an index for potential runoff from this strategic area.

By its very nature, forecast accuracy diminishes rapidly over time and over distance, i.e., the more long-range the forecast, the less reliability can be attached to it. In addition, none of these river flow forecasts from upstream will be able to predict the exact combination of high flows, ice jams and pressure ridge interaction in the vicinity of Vale Island. These three factors combined in different ways in 1963 and in 1985 to produce very different floods. In short, an upstream informational network will provide information on only one of the key elements in a typical Hay River flood - that of the magnitude of the flow coming down the river. Clearly, there is a need for interpretive or modelling techniques to include the other factors which combine to create floods in Hay River.

8.0 MITIGATION

By far the most comprehensive engineering study to date of mitigative works is found in the Stanley, Grimble, Roblin Ltd. (1959) report. The benchmark flood used for their largely hydraulic studies was the flood of 1951. The report contains five recommendations. The section reads as follows:

Recommendations:

> " An approximate economic analysis of the probable value of flood damage indicated that expenditures in the order of $250,000 - $500,000 in 1959 dollars, for flood control measures would be justified."
>
> " It is recommended that:
>
> (1) Vale Island be diked, using the Mackenzie Highway location through most of the townsite, to provide protection against water levels higher than those of the 1951 flood.
>
> (2) When the economic development of the town warrants it, the West Channel should be returned to its natural state, to provide flood relief by carrying ice and water away from the townsite.
>
> (3) Arrangements be made with the Department of Public Works, to carry out channel improvements in the East Channel of the Hay River, on a "spare time" basis.

(4) An experimental hydraulic land-fill project be carried out in co-operation with the Department of Public Works.

(5) Zoning regulations should be enacted to control building construction in the area between the dike and the river bank."

These recommendations derive from the explicit undertaking made clear elsewhere in the report, which was to provide protection for what is termed "Old Town" in their report. By their criteria, the flood of 1985 was a non-event because West Channel broke out ahead of East Channel and Old Town was unaffected.

A second engineering study was commissioned in 1977 to Underwood McLellan Ltd. to develop flood risk lines for purposes of the Flood Damage Reduction Program. Since this was a task-specific study, the report contains no recommendations for the safe-guarding of life and property in Hay River. It does however, develop certain design flood criteria in terms of water elevations which could be applied in design of mitigative works.

Specific criteria and assignments which this technical study addressed read as follows:

(1) Open water with a flood flow having an estimated return period of 100 years (1% probability of exceedence).

(2) Spring break-up with a flood flow having an estimated return period of 100 years (1% probability of exceedence) combined with an ice jam having a return period of 100 years.

(3) Spring break-up with a flood flow having an estimated return period of 20 years (5% probability of exceedence) combined with an ice jam having a return period of 20 years.

(4) Spring break-up with an ice jam having a return period of 20 years (5% probability of exceedence) and an open water flood flow having an estimated return period of 100 years (1% probability of exceedence).

(5) The historic flood of 1963, resulting in high water levels throughout the study area.

The focus of this study in Hay River has also shifted - from a concern by Stanley, et al, to design protective works for Old Town to "the sensitivity of the 'new townsite' area to flooding, as a consequence of both severe open water floods and ice jams" (p. 1-1).

Some of the more significant results of their study are summarized as follows:

- Synthesized flood peaks were generated for the period 1936 to 1963 by correlating meteorological data to record peak flow events.

- Regional flood frequency curves could not be developed because adjacent watersheds have dissimilar meteorologic and physiographic conditions.

- Design criteria for ice jam regime for lower Hay River were established from 1951 and 1956 flood events.

- Locations for severe ice jams were established.

- Vale Island can be expected to be periodically subjected to flooding, caused by ice jams in either the East or West channel as the Hay River discharges into Great Slave Lake during the spring breakup.

The FDR Technical Committee report (IWD, 1983) states that the defined frequency of occurrence for theoretical floodlines developed by Underwood McLellan in 1978 were too uncertain to be used to define Hay River flooding on Vale Island. In addition, the 1963 flood exceeded the Underwood McLellan theoretical design flood. Further hydraulic research was consequently undertaken by the FDR Technical Committee. A summary of the findings reads as follows:

- Two historic floods, those of 1963 and 1974, were used in combination to develop flood lines on Vale Island.

- The 1963 flood was an East Channel flood; the 1974 flood was a West Channel flood. The very high water levels generated by both events were suspected to be caused by grounded ice jams at the mouths of the respective channels.

- None of the floods considered will affect New Town.

9.0 THE 1985 FLOOD IN THE CONTEXT OF HISTORIC STUDIES AND THE FDR PROGRAM

Reviews of the background documents and examination of the extent of flooding in 1985 both support the conclusion that this flood was a West Channel event. In the perspective of Stanley, et al, (1959), this therefore was a desirable turn of events. Old Town was not flooded because the ice in East Channel remained stable through the critical periods of May 6 and 7. A number of historic events followed this pattern as well. Up to 1958 the West Channel floods have been documented by Stanley (1959). The strength of the ice cover in East Channel and the hydraulic conveyance capability of that channel with an intact ice cover appears to be a key determinant on the location of ice jam floods in West or East channels. The volume of flow at time of breakup would impact on East Channel ice stability and also influence the competence of the West Channel to carry significant volumes of the ice available from upstream.

Table 6 identifies where significant spring breakup events impacted on Vale Island.

A remarkably similar sequence of events occurred in the 1974 and the 1985 floods. In both years the East Channel ice remained firm and unbroken below Island D and initial movement of ice from upstream was down West Channel. In both years a pressure ridge offshore triggered a massive jam at the lake front. In 1974 the river mouth jam was blasted, which brought about the release of the jam and caused an immediate lowering of water levels along West Channel; in the words of Red

1904 - East Channel Flood
1914 - East Channel Flood
1918 - West Channel Flood
1936 - West Channel Breakup
1937 - West Channel Flood
1947 - East Channel Flood (West Channel blocked by road bed, washed out)
1950 - East Channel
1951 - East Channel Flood
1954 - West Channel (road bed fill in West Channel washed out)
1955 - West Channel Breakup
1957 - East Channel Breakup
1958 - West Channel Breakup (jam at river mouth)
1963 - East Channel Breakup
1964 - West Channel
1965 - West Channel first then East Channel four days later
1974 - West Channel Breakup

Table 6: Location of Breakup Impacts on Hay River (after Stanley, 1959)

McBryan, ".... as if someone had pulled the plug on the bathtub." One difference between the 1974 and 1985 floods was in water volumes during the critical flood periods. WSC records show that flows for the week preceding East Channel clearing were as shown in Table 7.

1974				1985		
Discharge	Date	Events	Day	Discharge	Date	Events
283	Apr. 27		D^{-7}	313	Apr. 30	
425	Apr. 28		D^{-6}	287	May 01	
626	Apr. 29		D^{-5}	542	May 02	
637	Apr. 30		D^{-4}	511	May 03	start of W.C. flooding
708	May 01		D^{-3}	861	May 04	release at lakeshore
963	May 02	ice blasted	D^{-2}	1 000	May 05	at midnight W.C. low
1 180	May 03	W.C. flood over	D^{-1}	1 350	May 06	
1 120	May 04		D^{0}*	1 310	May 07	major flood surge

* D^{0} = Day ice was clear of East Channel

Table 7: 1985 and 1974 flows in the week prior to East Channel clearing

9.1 Factors which Contribute to Hay River Floods

(1) Antecedent Climatic Conditions

a) Soil moisture conditions at the time of freezeup in the preceding autumn are a contributing factor to volumes of surface runoff the following spring. Models of snowmelt floods in the Red River basin in North Dakota and Manitoba suggest that fall soil moisture explain about 10% of the succeeding year's spring runoff. Regular monitoring of this condition at selected points in Hay River basin would provide some early indicators for flooding potential. It is, however, only one of many factors. Drews (1986) indicates that near-saturated soil moisture conditions were prevalent in Hay River basin in October, 1984.

b) Snow accumulation in a northern river basin is another prime indicator of flooding potential in the following spring. In Hay River basin, most of the climate stations which measure snow are located at towns near the main stem of the river and not in the high ground of Caribou Mountains or the Cameron Hills. Strategic location of new sites to measure snow before the melt would greatly enhance the prediction value of this climatic variable. Snow data can be available well in advance of a spring flood.

c) Precipitation during the melt period has been considered by many researchers to be a vital element in the generation of above average floods. This was the case in Hay River basin in 1985 (Drews, 1986). Because of the short time span between typical spring rainstorms and floods, its value as a forecasting tool is diminished, even when its presence or absence often spells the difference between a catastrophic or average flood event.

d) Protracted cool weather followed by very warm temperatures generally produce the exceptional floods.

(2) Ice Conditions

a) River ice conditions are significant to severity of flooding in Hay River. Two descriptors of river ice conditions suggest themselves as useful predictors for spring floods in Hay River. The first is ice thickness - data which are readily obtainable well in advance of a flood event. The second factor is the degree of thermal degradation of the river ice sheet just before the onset of breakup. Since ice jams are such an important element in perennial floods at Hay River, previous knowledge of river ice conditions would become a useful indicator of flooding potential.

b) The location and size of the annual ice pressure ridge, in the near-shore of Great Slave Lake helps to define flood potential on Vale Island. Large ice pressure ridges close to West and East channel river mouths can produce severe flood events. It was river mouth ice jams in 1963, 1974 and 1985 which caused much of the flood damage in those years.

(3) Flow Volumes

Large flow volumes play a significant role in flooding severity at Hay River. Large flows can be attributed to preceding climatic conditions and can often be identified before they become evident at Hay River. Earliest warning frequently can be obtained from flood flows upstream in the Chinchaga River, on Hay River at Meander River, on Steen River and other tributaries. These systems did not provide warning of the record high flows of 1985 spring, however. Most of the very high flows appeared to have their source in the Caribou Mountains.

The new gauging station just below Indian Cabins at 60°N, 07OB008, would include the runoff from the high ground and provide some measure of warning to Hay River residents. A much shorter warning is available from flow conditions at the WSC station, 07OB001, just above the Pine Point bridge. In 1985 the ice jam released at 23:00 on May 6 and serious flooding in West Channel occurred between 02:00 and 03:00 on May 7.

(4) Flood Timing

Analysis in a previous section of dates of ice out in East Channel showed the average annual date of ice out to be May 7. It is significant that all but one of the major floods in Hay River occurred on or just before that date. The exception in 1947 was the least significant flood of the eight shown in Table 8. All the pre-conditions for a severe flood appear to be optimized when the breakup occurs in the first week in May. In 1985, the spring rise began 10 days ahead of the peak flow. Such information might be of use in flood warning systems, but its variability needs further analysis.

Year	Date East Channel Clear
1985	May 07
1974	May 04
1963	May 05
1951	May 06
1947	May 10
1934	May 02
1914	May 02
1904	May 05

Table 8: Timing of Severe Floods in Hay River

9.2 Flooding Potential Indicators Summary

(1) Antecedent Moisture Conditions in Previous Autumn

Saturated soil conditions from heavy fall rains were identified in the Hay River basin in the fall of 1984. A greater portion of the subsequent spring melt would therefore be available for surface runoff. This condition can be assessed during or just after the freezeup.

(2) Snow Accumulation Prior to Melt

Knowledge of the water content of snow provides a measure of warning for impending high flows. It is essential to assess this factor in major contributing areas of the upstream river basin. In 1985, knowledge of snow water content in the Caribou Mountains near the end of April would have provided useful early warning of subsequent events.

(3) River Ice Conditions

Ice thickness data, and from this, ice strength, can be acquired from surveys in late March - early April. Samples could be taken at the WSC station above Pine Point Bridge and at four or five sites in East and West channel. Assessment of river ice strengths in the last week in April or the first few days in May are essential as input into ice jamming potential.

(4) Great Slave Lake Ice Conditions

Creation of an ice pressure ridge in offshore lake ice is a dynamic event. Its location and size needs measurement just before the breakup.

(5) River Flow Volumes

The size of the spring flood is a vital part of any assessment of flooding potential. Indications of flow magnitude can be obtained from river level and flow conditions on the Chinchaga River, and Hay River stations at Meander River, at the Alberta/NWT border and at the Pine Point Highway bridge. Advance warning times decrease as you get closer to Hay River. Chinchaga conditions would provide approximately one week's warning, the NWT border station over 30 hours and the Pine Point Highway station about 3 to 4 hours. In 1985, the Chinchaga River information did not provide any warning of exceptional floods because the source of flood waters was farther downstream.

(6) Melt Season Weather Forecasts

Three to five day synoptic weather forecasts are now fairly common in North America. Knowledge of an impending rainstorm event two days in advance would be valuable in assessing potential floods in Hay River.

For an exceptionally high flood to occur, all of these six elements must be present with above average values. They were in 1985.

10.0 CONCLUSIONS AND RECOMMENDATIONS

As mentioned in the previous section, all the elements for a serious flood at Hay River were present in the river basin in 1985.

The very high flows associated with the early morning flood of May 7 was almost certainly linked to the release of a large ice jam in the vicinity of the WSC station above Pine Point Bridge. Just after release of the jam at 23:00 on May 6, river flows were estimated in excess of 1 700 m^3/s. The mean daily published discharge of 1 350 m^3/s is a new historic high flow. Analysis in this report shows that the very high flows of May 6-8 had their origin in the Caribou Mountains of the lower basin. There were no exceptionally high river flows in the upper basin above Meander River station on the main stem Hay River.

The fact that the flood occurred mostly along West Channel rather than East Channel seems to have been caused by local ice conditions - river ice in the East Channel was sufficiently strong to remain relatively intact until after the major flood event of May 7. The very high water experienced along the West Channel, especially in the Fishing Village was caused principally by a grounded ice jam at the river mouth. The river mouth ice jam appears to have been formed where it was because of the ice pressure ridge location.

Comparison of the flooded area on Vale Island with the FDR flood map shows that those areas which were designated in 1983 were not flooded in this event. In fact, combination of the two flood events suggests that all of Vale Island is flood prone, but that individual annual events are highly variable. Greatest cause for variability arises from flood water routing down East or down West channels.

The timing of the annual flood in Hay River is a critical element which contributes to its severity. Eighty-nine years of ice out record for East Channel show that the earliest ice-out day was April 22; the latest was May 23 and average ice-out day was May 7. The eight largest floods since 1900 had ice-free conditions between May 2 and May 10, with seven of them between May 2 and May 7.

In addition to the timing of major floods in a calendar year, there is also a certain consistency in the year of occurrence of major floods over the historic record. Notable floods took place in 1951, 1963, 1974 and 1985. Anyone want to bet on 1996?

Certain recommendations can be derived from the events of 1985:

(1) The history of flooding on Vale Island is such that building of homes on the island can not be recommended. The same is recommended for commercial structures whose presence at the waterfront is not essential. This recommendation could be modified by the redesignation of Vale Island, based on the 1963, 1974 and 1985 floods.

(2) Given the level of development along both East and West Channel, it is recommended that benefits and costs of ice pressure ridge removal be analysed, especially when they are large and close inshore at

the mouths of East and West Channels.

(3) It is recommended that WSC and other government agencies work in cooperation with Hay River EMO office during the annual spring breakup period to provide as much advance warning as possible to Hay River residents.

(4) It is recommended that federal and territorial government agencies develop adequate data collection services to provide reliable information on:

a) Antecedent moisture conditions.

b) Snow water content just before the spring melt throughout the basin but especially in the Caribou Mountains.

c) River ice conditions upstream and in East and West channels.

d) Location and size of the ice pressure ridge offshore in Great Slave Lake in mid-April.

e) Upstream river flows or levels on a real-time basis at least at the following locations:

1. Hay River at Pine Point bridge.
2. Hay River at Alta/NWT border.
3. Hay River at Meander River.
4. Caribou Mountains tributary to Hay River.

f) Water levels at selected points in the town of Hay River during the spring flood.

g) Anticipated weather conditions through routine issuance of 5, 10 and 30 day weather forecasts.

When historic floods before 1970 occurred as events down West Channel, they were considered to be 'good' floods because they did not affect settled parts of Hay River. The social and economic impact of the 1985 West Channel flood suggests a changed pattern of land use on Vale Island. This fact increases the likelihood of spring breakup floods with threats to life and property.

11.0 REFERENCES

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APPENDIX A

Summary of Historical Flood Events, Hay River, N.W.T., 1904-1974

DATE	CAUSE	CHRONOLOGY	WATER LEVEL EXTENT	SOURCE OF FLOOD LEVEL INFORMATION
28 April, 1904	ice jam during spring breakup	27 April - Hay River breaks up quietly, no driftwood	much of Old Indian Village flooded	Diamond Jenness report on flooding (1978)
		28 April - ice jam at mouth backs water over banks and floods point up to RC cemetery - water covers RC potato field and garden to depth allowing skiffs to be paddled over fence	158.7 - 159.3m	Anglican & Catholic Mission records Article by Hay River teacher (1903-1909)
04 May, 1911	ice jamming	04 May - breakup in early morning - water overflowed banks in some places, and came to RC mission fence	limited overbank flooding 158.0 - 158.5m	Anglican/RC Mission records
01 May, 1914	ice jamming	30 April - breakup started in evening, water overflowing river banks and flooding Anglican mission grounds	flooding of lower parts of Village 158.5 - 159.3m	Anglican/RC Mission records
		01 May - around 02:30 water rose quickly into Anglican mission house (halfway across floor) and across grounds to stable and fish shed and flooded RC church above floor level		
		02 May - after receeding, water rose again @ 05:30 and then was released when West Channel broke up		
01 May, 1923	ice jamming	29 April - West Channel ice breaks up 01 May - ice broke around 16:00, jammed and water rose over banks on Anglican potato grounds	limited overbank flooding	Anglican Mission records

DATE	CAUSE	CHRONOLOGY	WATER LEVEL EXTENT	SOURCE OF FLOOD LEVEL INFORMATION
03 May, 1932	ice jamming	02 May - ice broke and jammed above Village, backed water up 03 May - jam at mouth, water backed up to top of banks	no overbank flooding 157.0 - 157.5m	Anglican Mission records
09 May, 1933	ice jamming	09 May - ice started to break around 16:00, mass movement by 19:00 - water rose to partly cover Mission and Vale Islands	limited overbank flooding 157.5 - 158.5m	Anglican Mission records
02 May, 1934	ice jamming	02 May - ice breakup began in early morning, overflowing bank by 02:00 and covering Anglican school field - water knee high at 3rd dog corral - water dropped quickly	overbank flooding 158.5 - 159.0	Anglican Mission records
10 May, 1947	ice jamming	07 May - jamming causes water to rise rapidly at 03:30 - breakup on West Channel, fill at head of Vale Island washed out 10 May - ice running in East Channel around 04:00, but jam at mouth backed water half way to RC Mission house before jam released	limited overbank flooding 158.4 - 159.0m	Anglican/RC Mission records

DATE	CAUSE	CHRONOLOGY	WATER LEVEL EXTENT	SOURCE OF FLOOD LEVEL INFORMATION
06 May, 1951	ice jamming	23 April - initial breakup and minor flooding near Fisheries fill 26 April - ice broke near mouth of river (YK Transportation Co. to Menzies fish plant) 03 May - heavy rain opens shore leads 04 May - main river break begins around 21:00, flooding in Old Town and car horns heard 05 May - all quiet in morning, mail plane unable to land at airport at 14:00 - most of NW-SE runway flooded (up to 1.2m depth) but NE-SW runway barely touched 06 May - at 02:00 waters rise to within 5m of RC Mission - water rises again at 04:00 (3 in. away), then receeds - most of Old Town flooded, one man drowned 07 May - ice moving and water dropping	major flooding in Old Town 158.5 - 159.0m (Indian Village) 159.0 - 160.0m (Old Town)	Anglican/RC Mission records
27 April, 1952	ice jamming	27 April - river jammed at mouth, flooding Old Town from HBC flats to mouth - water flush with banks at Indian Village 28 April - water rises as ice run from upstream comes down 29 April - jam breaks and water receeded	limited flooding 157.6 - 158.1m (Indian Village)	Anglican/RC Mission records

DATE	CAUSE	CHRONOLOGY	WATER LEVEL EXTENT	SOURCE OF FLOOD LEVEL INFORMATION
10 May, 1957	ice jamming	01 May - surges due to jamming and releases as river breaks up - fisheries staff house had 6 inches (0.15m) water 10 May - jam causes flooding to 4 feet (1.2m) at gov't wharf and YK Trans. Co. shipyards, over 50% short airport runway, flooded near Fisheries fill - minor flooding in West Channel 11 May - road flooded at sharf and signals corner - river side of road flooded from signals corner to mouth - water level above 160.3m at Fill D		Hay River File, EMO
03 May, 1963	ice jamming, mouth of river agravated by lake ice pressure ridge	27 April - breakup starts 30 April - some flooding in Old Town as ice jam 23 miles upstream breaks 01 May - flood crest hits Hay River, communications cut @ 07:40 - evacuation begins around 15:00 02-05 May- evacuation continues - several rises occurs in water levels, with water reaching to at least 161.5m at the Hay River Hotel and 160.0m further inland (St. Paul's school)	major flooding in Old Town and Indian Village 160.0 - 161.5m (Old Town)	The Hub, May 3, 1973 (10th Anniversary Issue)

DATE	CAUSE	CHRONOLOGY		WATER LEVEL EXTENT	SOURCE OF FLOOD LEVEL INFORMATION
03 May, 1963			- entire point flooded at Old Indian Village, with residents seeking refuge at Sandy Creek Camp, Great Slave Lake	160.5 - 161.0m (Old Indian Village)	F. Norn, personal recollection
02 May, 1974	ice jamming	30 April	- ice broke in West Channel before noon	159.3m (West Channel)	The Hub, May 8, 1974 Newspaper photo of flood and high water mark, C. Bird garage, oil mark on inside of garage
			- jamming occurring in both channels during the day, with some flooding back of Hay River Hotel and to highway in front of pool hall and in NTCL freight yard		
		01 May	- flooding in West Channel area starts late in day, residents evacuated		
		02 May	- jam located and blasted at 20:30, with immediate drop in water level		
		03 May	- residents allowed to return in morning		
			- East Channel ice starts to move in afternoon, NTCL barges behind Island A carried out into lake		
		04 May	- breakup over		

APPENDIX B

Record of WSC Measurements and Observations at Hay River, N.W.T., Spring, 1985

Environment Canada / Environnement Canada
Environmental Conservation / Conservation de l'environnement

WSC Discharge Measurements and Observations

Station Name / Nom de la station: Hay River and Vicinity, Spring, 1985
Station No. / Nº de la station: Various
For the year / Pour l'année 1985

Date Time (MST)	Location	Temp. Air °C	Temp. Water Eau °C	Width Largeur m	Area Superficie m²	Mean velocity Vitesse moyenne m/s	Mean Gauge Height Hauteur d'eau moy. m	Discharge Débit m³/s	Shift or B.W. from Stage Discharge Table / Décaler ou remous d'après la table de relations hauteur-débit. Table No. 4 m	Table No. 4 %	Table No. 5 m	Table No. 5 %	Remarks/Remarques
Jan 11	Hay River near Hay River, 070B001						2.016	8.39	-0.547				Backwater
Mar 06	Hay River Near Hay River, 070B001						1.892	2.43	-0.716				Backwater
Apr 19	Hay River near Hay River, 070B001	0	0	70.0	39.3	0.112	1.980	4.40	-0.691				Backwater
May 01 1700-1800	Hay River near Hay River, 070B001	15	3	128	491	0.772	5.115	379	-0.909				Backwater, water quality and sediment samples taken, ice out at approx. 1530 MST, huge jam downstream of gauge, solid ice in centre stream 500m above gauge, jam downstream of bridge is solid.
May 02 0825-0925	Hay River near Hay River, 070B001	7	1	128	503	0.819	5.503	412	-0.953				Backwater, last vertical not possible as ice broke upstream, steady bank to bank ice flow.
1405-1420	Hay River near Hay River, 070B001	15	2				5.981						Visit, found recorder off [uncalibrated], due disturbance to orifice line, reset. Believe orifice block torn off, orifice still functioning, unable to repair due running ice. Ice pans jammed below gauge, backed up to gauge in time of visit.

067-2122-M (09/81)

WATER RESOURCES BRANCH/DIRECTION DES RESSOURCES EN EAU

Environment Canada
Environmental Conservation

Environnement Canada
Conservation de l'environnement

WSC Discharge Measurements and Observations

Station Name / Nom de la station: Hay River and Vicinity, Spring, 1985

Station No. / Nº de la station: Various

For the year / Pour l'année 1985

Date (MST)	Location	Temp. Air °C	Temp. Water Eau °C	Width Largeur m	Area Superficie m²	Mean velocity Vitesse moyenne m/s	Mean Gauge Height Hauteur d'eau moy. m	Discharge Débit m³/s	Shift or B.W. from Stage Discharge Table Table No. 4 m	Table No. 4 %	Table No. 5 m	Table No. 5 %	Remarks/Remarques
May 02	West Channel near Mouth	15	3										Water running over ice onto lake held back by pressure ridge.
1600													Water in channel flowing into weeds and small trees along river
													bank.
May 03	Hay River near Hay						6.849						
0730	River, 07OB001												
0800-0900	Hay River near Hay	8	3	145	709	0.910	6.748	645	-1.535				Backwater, gauge clear of ice,
	River, 07OB001												small amount of frazel ice
													flowing, thin ice along edges. Huge release downstream 3/4 of
													way through measurement. Stage dropped 0.8m, stopped as mmnt.
													ended, then increased 0.25m and settled down. Downstream jams
													and releases continuous? Water quality and sediment samples
													taken.
1900	Great Slave Lake at Hay						1.770						
	River, 07OB002												
2400	Great Slave Lake at Hay						1.688						
	River, 07OB002												

Environment Canada Environnement Canada
Environmental Conservation Conservation de l'environnement

WSC Discharge Measurements and Observations

Station Name / Nom de la station: Hay River and Vicinity, Spring, 1985
Station No. / Nº de la station: Various
For the year / Pour l'année 1985

Date (MST)	Location	Temp. Air °C	Temp. Water Eau °C	Width Largeur m	Area Superficie m²	Mean velocity Vitesse moyenne m/s	Mean Gauge Height Hauteur d'eau moy. m	Discharge Débit m³/s	Shift or B.W. from Stage Discharge Table / Décaler ou remous d'après la table de relations hauteur-débit. Table No. 4 m	Table No. 4 %	Table No. 5 m	Table No. 5 %	Remarks/Remarques
May 04	Hay River near Hay						8.608						
0950	River, 07OB001												Steady since 0300 ± 0.050m,
													complete ice jam at gauge above and below, small pans and frazel
													ice, not moving. Orifice appears to be moving often.
1025	Great Slave Lake at Hay						1.698						
	River, 07OB001												
1500-1600	West Channel	5	2										River jammed solid with ice from mouth to gauge near Paradise
(approx.)													Gardens [07OB001]. Marked high water at various locations.
	East Channel												Water flowing 25% open (40') along left bank [Island "D" from
													illustration]. Ice jammed at West Channel Bridge to channel
													mouth.
	Great Slave Lake at												Water on ice on lake both sides of pressure ridge - if ridge
	water pumping station												was acting as a dam it no longer is.
May 05	Hay River near Hay	4	1				8.783						Ice jam as yesterday, no apparent movement. Gauge working good.
1155	River, 07OB001												

Environment Canada / Environnement Canada
Environmental Conservation / Conservation de l'environnement

WSC Discharge Measurements and Observations

Station Name / Nom de la station: Hay River and Vicinity, Spring, 1985
Station No. / Nº de la station: Various
For the year / Pour l'année 1985

Date (MST)	Location	Temp. Air °C	Temp. Water Eau °C	Width Largeur m	Area Superficie m²	Mean velocity Vitesse moyenne m/s	Mean Gauge Height Hauteur d'eau moy. m	Discharge Débit m³/s	Shift or B.W. from Stage Discharge Table / Décaler ou remous d'après la table de relations hauteur-débit. Table No. 4 m	Table No. 4 %	Table No. 5 m	Table No. 5 %	Remarks/Remarques
May 06	East Channel												Ice has jammed 1/2 way down to lake from West Channel Bridge
0700													since midnight. Ice push even with top of road.
0715-0745	East Channel above Island "D" and												Jammed ice even to top of road in places.
	West Channel in vicinity of Bridge												
0750	West Channel Fishing												Water 1 decameter below May 04 high water marks.
	Village												
0915	Hay River near Hay	10	2				8.576						Ice moved out. River flowing ice and debris on right half,
	River, 07OB001												open on left, ice piled on banks. Large orifice movement,
													can't tell if line torn out.
1100(approx)	Hay River near Hay						9.480±.1						Water Peaked (chart)
	River, 07OB001												
1205	Hay River near Hay						8.690						Ice still running. Level dropping 0.1m every 5 min.
	River, 07OB001												
1300(approx)	Hay River West Channel												ICE OUT

067-2122-M (09/81)

Environment Canada / Environnement Canada
Environmental Conservation / Conservation de l'environnement

WSC Discharge Measurements and Observations

Station Name / Nom de la station: Hay River and Vicinity, Spring, 1985
Station No. / N° de la station: Various
For the year / Pour l'année 1985

Date (MST)	Location	Temp. Air °C	Temp. Water Eau °C	Width Largeur m	Area Superficie m²	Mean velocity Vitesse moyenne m/s	Mean Gauge Height Hauteur d'eau moy. m	Discharge Débit m³/s	Shift or B.W. from Stage Discharge Table / Décaler ou remous d'après la table de relations hauteur-débit. Table No. 4 m	Table No. 4 %	Table No. 5 m	Table No. 5 %	Remarks/Remarques
May 06	Hay River Old Town	12	1										
	situation post break-up												Main (East) Channel ice pushed up onto road across from airport
													terminal right up to railroad tracks. Tracks under ice. (Houses
													across from airport have ice filled yards). Water pooling at
													end of road in Fisherman's Village up into low lying areas.
1440	Hay River near Hay	12	1				8.489						50% of river flowing free, 50% small pans and frazel.
	River, 070B001												
1830	Hay River near Hay						9.440						25% of river flowing small pans and frazel.
	River, 070B001												
2040-2155	West Channel Bridge			105	497	0.942	--	468 B					0.2, 0.6, 0.8 method used, flow at right angles to bridge, 19
													verticals used. River flowing open, approximately 3m of ice
													pans, frazel ice left stationary on banks.
2310	West Channel Bridge												West Channel ice free.

Environment Canada
Environmental Conservation

Environnement Canada
Conservation de l'environnement

WSC Discharge Measurements and Observations

Station Name / Nom de la station: Hay River and Vicinity, Spring, 1985

Station No. / Nº de la station: Various

For the year / Pour l'année 1985

Date Time (MST)	Location	Temp. Air °C	Temp. Water Eau °C	Width Largeur m	Area Superficie m²	Mean velocity Vitesse moyenne m/s	Mean Gauge Height Hauteur d'eau moy. m	Discharge Débit m³/s	Shift or B.W. from Stage Discharge Table / Décaler ou remous d'après la table de relations hauteur-débit. Table No. 4 m	Table No. 4 %	Table No. 5 m	Table No. 5 %	Remarks/Remarques
May 07	Hay River Old Town												Water Flowing over road to Vale Island, ice flowing bank
0035													to bank at West Channel Bridge.
0050	Hay River near Hay												30% ice flows at gauge, declining stage.
	River, 07OB001												
0055	West Channel Bridge												30% ice flowing.
0910	Hay River near Hay	10	1				6.940						River flowing 25% frazel with occaisional small pan. Orifice
	River, 07OB001												unstable.
1140	Hay River near Hay						6.885						Installed new orifice in 6m of water. Ice as before.
	River, 07OB001												
1115-1235	Hay River near Hay	12	2	148	750	1667	6.883	1250			-0.472		Backwater, lots of debris
	River, 07OB001												flowing on right half (20%),
													left half clear, wet line correction applied.
1530-1715	West Channel Bridge	15	2	108	504	0.933	--	470 B					0.2, 0.8 method used, flow at right angles to bridge, 20% flowing
													ice, occaisional ice [pans ?].

Environment Canada — Environnement Canada
Environmental Conservation — Conservation de l'environnement

WSC Discharge Measurements and Observations

Station Name / Nom de la station: Hay River and Vicinity, Spring, 1985
Station No. / Nº de la station: Various
For the year / Pour l'année 1985

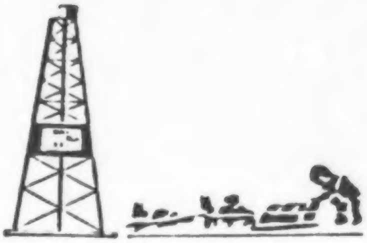
Date Time (MST)	Location	Temp. Air °C	Temp. Water Eau °C	Width Largeur m	Area Superficie m²	Mean velocity Vitesse moyenne m/s	Mean Gauge Height Hauteur d'eau moy. m	Discharge Débit m³/s	Shift or B.W. from Stage Discharge Table / Décaler ou remous d'après la table de relations hauteur-débit. Table No. 4 m	Table No. 4 %	Table No. 5 m	Table No. 5 %	Remarks/Remarques
May 08	Hay River near Hay	8	1	145	680	1.809	6.365	1230			0.001	0.0	River flowing completely
0905-1020	River, 07OB001												open, orifice possibly silting
													over. Section has scoured
	West Channel Bridge	16	1										Both channels flowing free of ice as far as the eye can see.
													Water level has dropped 1 1/2 metres.
May 10	Hay River near Hay	15	3	150	674	1.810	6.314	1220			0.030	0.8	Orifice moved. Painting
1430-1540	River, 07OB001												trace indicates water
													surging?
May 14	Hay River near Hay	18	2	146	631	1.743	6.052	1100			-0.002	0.0	5 sediment samples taken.
1230-1345	River, 07OB001												
June 04	Hay River near Hay						3.605	310			-0.014	1.6	
	River, 07OB001												
July 30	Hay River near Hay						2.770	146			-0.032	3.3	
	River, 07OB001												

APPENDIX C

A.E.S. Report on the Hay River Flood, May 1985,

M. D. Drews

SCIENTIFIC SERVICES
A.E.S. WESTERN REGION



REPORT

86-1

HAY RIVER FLOOD

MAY 1985

M. D. DREWS

February 1986

SCIENTIFIC SERVICES
A.E.S. WESTERN REGION

ABSTRACT

During early May 1985 snowmelt runoff combined with rain and ice jams to cause flooding in the town of Hay River and other sections of the Hay River basin. The meteorological conditions preceding and relating to the event are examined including temperature and various precipitation analyses.

ACKNOWLEDGEMENTS

The help provided by J. Ross in the running of computer programs and plotting of figures is gratefully acknowledged. The enlightening slides, notes and comments relating to snow and weather conditions over central areas of the Hay River basin, as provided by H. Reynolds and J. McGillis of the Canadian Wildlife Service, are acknowledged with thanks.

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Figure 2 Hay River Temperature and Precipitation September 1984 to May 1985

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METEOROLOGICAL CONDITIONS PERTAINING TO THE HAY RIVER FLOOD OF MAY 1985

1. INTRODUCTION

On May 7, 1985 snowmelt runoff from the Hay River basin combined with ice jams to cause life-threatening flooding in the town of Hay River. Compensation payments for the damage exceeded half a million dollars. This report discusses the meteorological factors which contributed to the flooding.

Attempts to describe weather conditions throughout the Hay River basin are hampered by a lack of year-round weather observation stations. Except for the Hay River airport station at the mouth near Great Slave Lake, and the Hay River Paradise Gardens climate station just to the south, there are no continuously reporting stations within the basin (Figure 1). Reports from Meander River (UH) for the months October '84 through March '85, and from Rainbow Lake Ranger Station (RB) for January and February '85 provide the only precipitation information for a point within the basin for a reasonable period. Besides Hay River airport (YHY), the nearest official airport observing stations (all outside the basin) are High Level (YOJ), Ft Nelson (YYE), Ft St John (YXJ), and Peace River (YPE). There is also a network of Alberta Forestry Service (AFS) and Parks Canada Lookout towers in Alberta and Canadian Forestry Service (CFS) towers in the Northwest Territories, but these stations close in late August or early September and do not re-open until late April or in May.

Much of what follows in this description of the monthly and seasonal precipitation patterns must therefore be used with caution because except for data near the mouth of the river, values for the basin itself had to be inferred and interpolated largely from data outside the basin.

2. ANTECEDENT CONDITIONS - FALL AND WINTER 1984-85

Table 1 provides an overview of temperature and precipitation for the fall to early spring at Hay River, High Level, and Ft Nelson airports. Freeze-up occurred about October 21 after which maximum temperatures remained essentially below melting until March except for a few days during January and briefly in February. Mean temperatures generally were below normal except for January, March, and April. The largest anomaly occurred in January 1985 when mean temperatures were eight to ten degrees above normal. Hay River airport on January 2nd established a record maximum of 10.7°C, eclipsing the previous 9.4°C set on January 31, 1935. Temperature observations at Hay River began in 1894. Mean temperatures in March were roughly five degrees above normal. During November, December, and February mean temperatures were some five to six degrees below normal.

Monthly freezing and thawing degree-days are shown in Table 1. These degree-days are tabulations of the differences between the daily mean temperatures and zero degrees Celsius. Negative values increase the freezing degree-day total while positive values contribute to thawing degree-days. These totals reflect the relatively mild temperatures of January and the cold conditions of December and February. Daily maximum temperatures and precipitation from September 1984 to May 1985 are plotted for Hay River and High Level airports in Figures 2 and 3, respectively.

Table 1 shows that precipitation was above normal for September (except just under normal at Hay River), October and February, but also in April at Hay River only. Below normal precipitation fell in November, December, January, March, and April. The most noteworthy anomalies occurred in October when Hay River received 267% of normal and High Level collected 329% of its normal precipitation. The relatively large precipitation amounts during September and October ensured saturation of the ground prior to freeze-up.

Figures 4 to 11 are precipitation analyses for the months September 1984 to April 1985. In Figure 4 noteworthy aspects for September are the 50 to 60+ mm over upper parts of the basin and 30 to 40 mm over lower sections. Additional information was obtained from conversations with Hal Reynolds and Joe McGillis of the Canadian Wildlife Service (CWS) who are conducting wood bison transplants to a compound near Habay. Their notes indicate the compound area was very wet in early October 1984, with 1 to 1.5 m of standing water in the area. The situation could not improve much throughout October when another 50 mm or so fell on the upper basin, while the lower basin received 70 to 80 mm of precipitation (Figure 5).

During November (Figure 6) snowfall ranged from 10 cm or less in the upper basin to 30-40 cm over lower parts. The pattern for December (Figure 7) was similar but amounts were slightly higher over upper sections and somewhat less over lower areas of the basin than in November. January's pattern (Figure 8) had low amounts of 11 cm over central areas of the basin near Meander River but higher accumulations in excess of 35 cm on the NWT side upstream from Hay River Paradise Gardens. February accumulations (Figure 9) again were lowest over central sections of the basin, but in the 30 to 45 cm range over upper areas.

Precipitation during March 1985 (Figure 10) was very low - roughly in the 5 to 10 cm range; Hay River airport received only 20% of its normal complement. April (Figure 11) raised precipitation amounts to 125% at Hay River, but central areas of the basin were quite dry. Upper sections received an estimated 10 to 20 cm of snow around the time of April 20-21 according to an aerial survey conducted by CWS on April 22.

Figure 12 displays accumulated precipitation and its corresponding percent of normal for September 1984 to April 1985, inclusive. The upper sections of the basin had received approximately 200 to 225 mm during these eight months. Lower areas had collected 225 to 250 mm which represents about 110 to 125% of normal for the period. Central parts of the basin had received the least precipitation, being biased by the 138 mm reported for Meander River. However, downstream run-off from the Caribou Mountains, and to a lesser extent from the Cameron Hills, undoubtedly compensated for the relatively smaller accumulations over central areas.

3. SNOWDEPTH DURING THE SPRING OF 1985

Figure 13 shows snowdepths at the end of January, February, March, and April 1985. The maximum snowdepth over most of the basin probably existed near the end of February, in conjunction with that month's above normal snowfall. Average depths likely were in the 50 to 60 cm range, but J. McGillis of the Canadian Wildlife Service observed depths of 71 to 76 cm, and some drifts up to 86 cm deep during February 26-28 near Habay in the CWS bison paddock.

A strong thaw occurred near the end of February when McGillis observed 12°C near Habay. Such very mild temperatures also were reported on the 27th from High Level: 12.2°C, Meander River: 9.0°C, Hay River Paradise Gardens: 10°C, and at Hay River: 9.4°C. The thaw also is evident on Figures 2 and 3 showing the maximum temperatures for Hay River and High Level airports, respectively. The value of 9.4°C at Hay River represents a record for February 27th, the previous was 8.9°C set first in 1938 and tied in later years. The monthly record maximum for February at Hay River is 13.9°C set on February 28, 1968.

A fairly steady rise in maximum temperatures occurred during March and April, and by the end of April 1985 snowcover had been depleted dramatically. Figure 13 shows only a 'trace' at High Level and 23 cm at Hay River airports. Meander River did not record snowdepth during March and April, but the Alberta Forestry lookout tower ZA near Zama Lake reported a depth of 41 cm when the tower was opened for the season on April 26. This depth increased to 43 cm by April 28th, but by May 1 Zama LO reported zero snowdepth.

It appears therefore that upper parts of the basin lost the snowcover much sooner than lower portions near the mouth of Great Slave Lake. Table 2 shows snowdepths at Hay River and High Level airports for the winter of 1984-85 along with comparative maximum values. The period of record is 30 years for Hay River beginning in 1955-56, but only 15 years for High Level beginning in 1970-71.

Snowcover at Hay River during the winter of 1984-85 was somewhat greater than the 30-yr mean during early winter until the end of December, and again after the end of March. Snowdepths on April 15 (40 cm) and April 30 (23 cm) were significantly greater than the means of 25 and 7 cm, respectively. It is important to note that the April 30th value was close to the 30-yr maximum of 26 cm for this date in 1979.

The 1984-85 season's maximum snowdepth at Hay River was 56 cm on February 22nd, this was lower than the 27-yr mean maximum of 67 cm for March 6 (some data were missing for 1962-63, 1979-80, and 1981-82). The record maximum depth of 122 cm occurred on January 31, 1962. At High Level the 1984-85 maximum depth was 86 cm on February 24th, this was higher than the 12-yr mean maximum of 64 cm for a mean date of February 21, and close to the record maximum depth of 89 cm of March 6, 1972 (some data for High Level were missing for 1970-71, 1979-80, and 1983-84).

Snowcover at Hay River airport persisted from October 25/84 to May 4/85 for a total of 192 days, slightly longer than the mean of 187 days. At High Level snowcover persisted from October 18/84 to April 19/85 for a total of 184 days, which also was longer than the mean of 169 days.

4. LATE APRIL TO EARLY MAY 1985

Figure 14 shows daily maximum and minimum temperatures, as well as daily snowdepth at Hay River airport from April 1 to May 10, 1985. Maximum temperatures reached above freezing every day after April 23, and the snowcover of that date was depleted quickly after April 24. Very rapid melt occurred on May 2 when 14 cm disappeared as maximum temperatures exceeded 10°C. Thawing degree-days (Table 1) in April at Hay River and High Level airports were 25.5 and 70.4, respectively. During May 1-6 thawing degree-days at Hay River and High Level were 24.3 and 42.9, respectively. These degree-day accumulations show that temperatures were higher, and the melt progressed more quickly, over upper parts of the basin in the south.

The rapid snowmelt of late April and early May was augmented by significant rainfalls during early May. Figure 15 depicts the precipitation pattern for the period May 1 to 7, but 90 to 100% of the rain over the basin fell May 3 to 5. The primary axis of precipitation stretched from Ft McMurray (YMM) to just east of Foggy LO (FG) to extreme northwestern Alberta. Upper portions of the Hay River basin received 5 to 15 mm, while lower parts collected 15 to 20 mm, and areas near the Northwest Territories border accumulated 25 to 30 mm.

The low pressure system which produced the rain during early May moved from central Alberta to Saskatchewan and a trough of low pressure extended to northwestern Alberta and southeastern Yukon. Figure 16 shows the relevant surface and upper air (500-mb) analyses for the afternoons of May 3 and 4.

5. SNOWMELT MODEL CALCULATIONS

Table 3 is a listing of 'Snowmelt Model 3' calculations for Hay River airport for the years 1943 to 1985. 'Snowmelt Model 3' is one of five models developed by the Hydrometeorology Division of the Canadian Climate Centre, Atmospheric Environment Service, Downsview. The model uses maximum and minimum daily temperatures as well as daily depth of fresh snow to calculate daily snowmelt estimates. The maxima of the combined rain plus snowmelt values are used to determine the annual maximum series for 1 to 30-day periods.

The annual maximum value series are then analyzed assuming a Gumbel extreme value distribution, and, using a method of moments fit, to derive extreme value estimates for return periods up to 100 years as shown in Table 4 for Hay River.

The values in Tables 3 and 4 indicate that in terms of snowmelt 1985 was not an extra-ordinary year for the Hay River airport location. The model suggests that basically the spring of 1985 produced snowmelt values which fell in the 2 to 5-year return period range. Other factors and effects such as earlier upstream melt and rainfall, plus ice jams therefore compensated to increase the flooding at Hay River.

'Snowmelt Model 3' also was run for High Level airport for the years 1971 to 1985. Table 5 shows the annual 1 to 30-day maximum snowmelt values, while Table 6 lists the return period amounts. At High Level the spring of 1985 produced snowmelt figures which generally also fall in the 2 to 5-year return period range. However, the shorter period of record of only 15 years indicates that calculated return period values greater than 25 years should be viewed with caution.

6. CONCLUSIONS

Weather conditions during September and October 1984 brought above normal precipitation and below normal temperatures to the Hay River basin. This resulted in fairly saturated ground conditions by the time freeze-up occurred late in October. Snowfall for the remainder of winter was below normal except for February, when maximum snowdepths were reported. The maximum depth of snow at Hay River airport was 56 cm on February 22nd, and the April 30th snowdepth of 23 cm at Hay River was close to the 30-yr maximum value of 26 cm for this date. Upper areas of the basin accumulated in the order of 70 to 85 cm of snow by late February.

Snow melted more rapidly and the snowcover disappeared earlier from the upper Hay basin than from lower sections. Very mild temperatures on May 1 and 2 followed by upstream rainfalls of 25 to 30 mm increased runoff to lower parts of the basin during the first week of May 1985. Since temperatures were cooler over southern Great Slave Lake throughout late April and early May, the northward flowing melt and rain waters from upper and central portions of the Hay River basin contributed to flooding near the mouth, where significant ice and ice jams were encountered.

7. RECOMMENDATIONS

As stated in the introduction, a lack of year-round meteorological stations within the Hay River basin makes it difficult to produce accurate precipitation analyses. Fire weather lookouts towers normally are closed relatively early in the fall if the fire danger is sufficiently low. Likewise they are not opened until late April or early May unless it is dry or there is an early fire weather threat from dry conditions. Therefore if precipitation is higher than normal in the fall and spring, fire weather lookouts likely will not stay open as late in the fall or open as early in the spring than if the fall and spring were dry. Information gathering is thus not favourable for runoff assessment and water management purposes.

Several options may be considered for obtaining necessary information in the future:

1) install precipitation storage gauges, preferably with data collection platforms

2) open one or more climatological stations - possible sites are Rainbow Lake, Chateh, Lutose

3) conduct routine aerial and/or ground snow surveys - install marked snow stakes at representative locations which may be read remotely from the ground and from the air

4) investigate snowcover mapping utilizing satellite data

5) seek avenues of cooperation with other agencies such as Alberta and Canadian Forestry Services, Alberta Environment, Canadian Wildlife Service, and Indian and Northern Affairs Canada to record and document snowdepth at regular and/or opportunistic intervals.

8. APPENDIX

Surface and 500-mb analyses were reproduced from microfilm of analyses prepared by Atmospheric Environment Service's Canadian Meteorological Centre in Montreal. Other maps and figures were produced in the Computer-Communications Centre and Scientific Services Division of the Atmospheric Environment Service in Edmonton.

Snowmelt calculations and snowdepth data were obtained using computer programs developed by the Hydrometeorology Division of the Canadian Climate Centre in Downsview, Ontario.

Alberta Forestry Lookout and Ranger stations are operated by the Alberta Forestry Service. Fire weather towers in Wood Buffalo National Park are operated by Parks Canada.

Table 1. Temperature and Precipitation September 1984 to April 1985
for Hay River, High Level, and Ft Nelson airports

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY 1-6
HAY RIVER A									
Mean Temp °C	6.9	-1.4	-16.2	-26.2	-17.1	-28.1	-11.6	-3.7	
Dep. from Normal °C	-1.2	-2.3	-4.8	-5.3	+8.7	-6.4	+4.7	+0.5	
Snowfall C M	0.4	52.1	20.1	17.1	15.4	26.1	3.7	17.2	
Total Precipitation M M	40.4	81.5	20.1	17.1	15.4	26.3	3.7	19.7	
Precip. as % of Normal	96	267	55	70	74	146	20	125	
Precip. Dep. from Normal M M	-1.9	+51.0	-16.8	-7.5	-5.4	+8.3	-15.8	+3.9	
Month-end Snow on Ground C M	0	12	27	39	40	53	44	23	
Freezing degree-days	0	122	487	813	523	786	360	135	0
Thawing degree-days	208	81	2.4	0	3.2	0	0.2	26	24.3
HIGH LEVEL A									
Mean Temp. °C	6.2	-2.0	-16.4	-26.6	-15.4	-24.0	-6.8	1.3	
Dep. from Normal °C	-1.9	-3.3	-5.0	-6.3	+9.2	-5.5	+5.0	+0.5	
Snowfall C M	2.0	37.6	22.3	21.7	15.5	39.2	13.6	2.0	
Total Precipitation M M	42.4	48.4	19.1	18.9	13.6	35.4	13.0	6.0	
Precip. as % of Normal	125	329	68	77	66	223	80	34	
Precip. Dep. from Normal M M	+8.5	+33.7	-8.8	-5.8	-7.0	+19.5	-3.2	-11.4	
Month-end Snow on Ground C M	0	25	32	49	50	50	30	TR	
Freezing degree-days	0	149	492	824	477	686	215	32	0
Thawing degree-days	185	88	0.8	0	0.5	2.6	5.0	70	42.9
FT NELSON A									
Mean Temp. °C	6.8	-2.2	-17.8	-24.0	-13.8	-22.5	-4.2	3.0	
Dep. from Normal °C	-1.9	-3.3	-5.8	-3.0	+10.0	-5.6	+5.6	+1.4	
Snowfall C M	TR	40.6	19.3	23.1	19.7	30.5	18.2	TR	
Total Precipitation M M	46.0	45.2	12.0	16.0	17.1	24.3	13.4	0.8	
Precip. as % of Normal	111	186	53	75	69	125	55	5	
Precip. Dep. from Normal M M	+4.4	+20.9	-10.7	-5.4	-7.8	+4.8	-11.0	-15.9	
Month-end Snow on Ground C M	0	4	19	29	35	50	25	14	
Freezing degree-days	0	145	535	744	430	636	143	1.1	0
Thawing degree-days	204	77	0	0	0	4.4	11.5	90	45.6

Table 2. Snowdepth (cm) Hay River and High Level airports
October 31/84 to May 15/85

	O31	N15	N30	D15	D31	J15	J31	F15	F29	M15	M31	A15	A30	MY15
HAY RIVER A														
1984-85	12	27	27	34	39	39	40	48	53	50	44	40	23	0
Mean (1955-85)	6	18	24	29	37	43	48	51	56	55	46	25	7	0
Maximum	41	74	76	81	99	104	122	102	102	107	97	61	26	3
Year	'66	'61	'61	'61	'61	'62	'62	'62	'62	'62	'67	'64	'79	'61
HIGH LEVEL A														
1984-85	25	35	32	45	49	37	50	59	50	26	30	10	0	0
Mean (1955-85)	3	11	21	30	35	39	43	47	50	42	31	10	1	0
Maximum	25	35	38	46	57	64	71	74	86	77	74	48	5	0
Year	'84	'84	'75	'75	'80	'73	'74	'74	'72	'79	'74	'72	'79	

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                                        ATMOSPHERIC ENVIRONMENT SERVICE
                                RAIN+SNOWMELT INTENSITY, DURATION, FREQUENCY VALUES
                          PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE
****************************************************************************************************************

STATION : HAY RIVER, N.W.T     (SNOWMELT MODEL 3)                                         STATION NUMBER  2202400

CRITICAL PERIOD :  1ST OF MONTH 10 TO THE END OF MONTH 5                               NOTE : MODIFIED GUMBEL 12/82
      TOTAL  %
YEARS DAYS VALID FLAG              1 DAY  2 DAY  3 DAY  4 DAY  5 DAY  6 DAY  7 DAY  8 DAY  9 DAY 10 DAY 15 DAY 20 DAY 25 DAY 30 DAY


1943  122   33  ** START DATE      21/11  21/11  21/11  21/11  21/11  16/11  16/11  16/11  16/11  16/11  16/11  16/11  16/11  16/11
                   MAX VALUE          56     56     56     56     56     64     64     64     64     64     64     64     64     64
1944  336   91     START DATE      10/ 4  10/ 4   9/ 4   9/ 4   9/ 4   9/ 4   9/ 4   9/ 4   9/ 4   9/ 4  28/ 3  28/ 3  28/ 3  28/ 3
                   MAX VALUE         352    542    659    659    659    659    659    659    659    659    983    983    983    983
1945  341   93     START DATE       2/ 5   2/ 5   2/ 5   2/ 5   2/ 5   2/ 5   2/ 5   2/ 5   2/ 5   2/ 5   2/ 5  14/ 4  14/ 4  14/ 4
                   MAX VALUE         150    150    150    150    150    150    150    150    150    150    150    168    168    168
1946  339   92     START DATE      20/ 4  19/ 4  13/ 4  12/ 4  12/ 4  15/ 4  14/ 4  13/ 4  12/ 4  12/ 4  10/ 4  10/ 4  10/ 4  10/ 4
                   MAX VALUE         174    241    257    273    273    391    402    498    514    514    572    572    572    605
1947  365  100     START DATE       1/ 5  30/ 4   1/ 5  30/ 4  29/ 4  28/ 4  27/ 4  27/ 4  27/ 4  27/ 4  28/ 4  27/ 4  27/ 4  14/ 4
                   MAX VALUE         142    250    345    453    532    602    688    688    688    688    729    815    815    880
1948  366  100     START DATE       6/ 5   2/ 5  30/ 4  30/ 4  29/ 4  28/ 4  30/ 4  29/ 4  28/ 4  27/ 4  22/ 4  22/ 4  22/ 4  22/ 4
                   MAX VALUE         253    332    493    608    699    792    861    952   1045   1094   1226   1226   1226   1226
1949  365  100     START DATE      22/ 4  21/ 4  21/ 4  21/ 4  18/ 4  18/ 4  18/ 4  18/ 4  18/ 4  18/ 4   8/ 4   5/ 4  31/ 3  24/ 3
                   MAX VALUE         191    268    301    359    458    491    549    549    549    549    600    842    933   1031
1950  365  100     START DATE      13/ 4  13/ 4  13/ 4  12/ 4  12/ 4  12/ 4  12/ 4  13/ 4  13/ 4  12/ 4  12/ 4  12/ 4  12/ 4  12/ 4
                   MAX VALUE         261    444    586    661    661    661    693    817    914    989    989   1140   1140   1140
1951  365  100     START DATE      28/ 4  27/ 4  27/ 4  27/ 4  27/ 4  27/ 4  27/ 4  26/ 4  26/ 4  26/ 4  26/ 4  26/ 4  26/ 4   1/ 4
                   MAX VALUE         233    416    575    640    722    817    939    981   1017   1017   1017   1017   1017   1106
1952  366  100     START DATE      15/ 4  15/ 4  14/ 4  14/ 4  12/ 4  11/ 4  10/ 4  10/ 4  10/ 4  10/ 4   4/ 4  28/ 3  28/ 3  28/ 3
                   MAX VALUE         342    680    813    813    904    928   1019   1019   1019   1019   1123   1261   1261   1350
1953  365  100     START DATE       5/ 4   4/ 4   3/ 4   3/ 4   2/ 4   2/ 4  30/ 3  30/ 3  28/ 3  28/ 3  25/ 3  25/ 3  28/ 3  25/ 3
                   MAX VALUE         240    439    588    645    701    701    719    776    827    884    917    917    952    985
1954  365  100     START DATE      18/ 5  17/ 5  16/ 5  15/ 5  14/ 5  13/ 5  13/ 5  11/ 5  10/ 5   9/ 5   5/ 5   3/ 5   3/ 5   3/ 5
                   MAX VALUE         410    635    750    799    874    899    899    999   1098   1156   1271   1346   1346   1346
1955  364  100     START DATE      15/ 5  14/ 5  13/ 5  13/ 5  13/ 5  13/ 5   9/ 5   8/ 5   8/ 5   8/ 5   2/ 5  26/ 4  23/ 4  23/ 4
                   MAX VALUE         444    824    923    923    923    923    932    997    997    997   1376   1409   1549   1552
1956  366  100     START DATE      23/11  18/ 4  11/ 4  23/11  11/ 4  11/ 4  12/ 4  12/ 4  11/ 4  11/ 4  11/ 4  11/ 4  11/ 4  11/ 4
                   MAX VALUE         183    285    342    397    482    482    540    668    776    776    919    919    919    919
1957  365  100     START DATE       3/ 5   2/ 5   1/ 5  30/ 4  29/ 4  28/ 4  27/ 4  27/ 4  27/ 4  27/ 4  19/ 4  16/ 4  16/ 4  16/ 4
                   MAX VALUE         212    270    420    437    584    669    822    822    822    822    855   1073   1090   1136
1958  365  100     START DATE       5/ 5   4/ 5   4/ 5   4/ 5   4/ 5   4/ 5   4/ 5   4/ 5  28/ 4  28/ 4  24/ 4  18/ 4  18/ 4   7/ 4
                   MAX VALUE         503    883   1124   1124   1124   1124   1124   1124   1290   1290   1331   1453   1453   1462
1959  365  100     START DATE      11/ 4  10/ 4   9/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4   9/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4
                   MAX VALUE         392    642    783    848    848    848    848    848    929    994    994    994    994   1018
1960  366  100     START DATE      24/ 4  24/ 4  24/ 4  23/ 4  23/ 4  23/ 4  20/ 4  20/ 4  18/ 4  20/ 4  18/ 4   9/ 4   9/ 4   4/ 4
                   MAX VALUE         233    458    633    790    824    824    973   1007   1040   1145   1212   1280   1418   1458
1961  365  100     START DATE      17/ 5  17/ 5  17/ 5  16/ 5  16/ 5  16/ 5  16/ 5  16/ 5  16/ 5  16/ 5   9/ 5   9/ 5  29/ 4  29/ 4
                   MAX VALUE         799   1234   1846   1963   1963   1963   1963   1963   1963   1963   1979   1979   2021   2021
1962  365  100     START DATE      23/ 5  22/ 5  21/ 5  20/ 5  19/ 5  18/ 5  17/ 5  16/ 5  15/ 5  14/ 5  12/ 5   7/ 5   7/ 5   7/ 5
                   MAX VALUE         528    807    975   1192   1374   1390   1661   1982   2073   2088   2434   2492   2492   2492
1963  358   98     START DATE       8/ 5   8/ 5   8/ 5  22/ 4  22/ 4  21/ 4  23/ 4  23/ 4  22/ 4  21/ 4  24/ 4  21/ 4  14/ 4  10/ 4
                   MAX VALUE         536    536    536    659    800    840    875   1074   1240   1280   1384   1816   1925   2290
1964  366  100     START DATE      17/ 5  16/ 5  15/ 5  14/ 5  13/ 5  12/ 5  11/ 5  11/ 5   9/ 5   8/ 5   3/ 5  29/ 4  24/ 4  21/ 4
                   MAX VALUE         245    457    657    892    917    945    978    978    985   1084   1709   2008   2132   2166
1965  365  100     START DATE      12/ 4  11/ 4  11/ 4   9/ 4   8/ 4  11/ 4  11/ 4   8/ 4   4/ 4   3/ 4  11/ 4   8/ 4   3/ 4   3/ 4
                   MAX VALUE         215    398    398    414    472    490    490    539    604    629    845    919   1076   1076
1966  365  100     START DATE       7/ 5   7/ 5   6/ 5   5/ 5   4/ 5   3/ 5   3/ 5   3/ 5   3/ 5   3/ 5   3/ 5  21/ 4  21/ 4  21/ 4
                   MAX VALUE         700   1080   1387   1478   1635   1927   1927   1927   1927   1927   1927   1992   1992   1992
1967  365  100     START DATE      13/ 5  12/ 5  12/ 5  12/ 5  12/ 5  12/ 5  12/ 5  12/ 5   5/ 5   4/ 5   4/ 5  28/ 4  22/ 4  21/ 4
                   MAX VALUE         666    874    974   1008   1125   1173   1180   1209   1280   1505   1811   2086   2146   2255
1968  366  100     START DATE      28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2  28/ 2
                   MAX VALUE         271    412    587    687    687    687    687    687    687    687    687    687    820    878
1969  365  100     START DATE      17/ 4  17/ 4  17/ 4  16/ 4  16/ 4  14/ 4  13/ 4  12/ 4  11/ 4  11/ 4   8/ 4  11/ 4   8/ 4   8/ 4
                   MAX VALUE         251    457    679    787    787    796    896   1079   1172   1172   1275   1608   1708   1708
1970  365  100     START DATE       1/ 5  21/ 4  21/ 4  21/ 4  21/ 4  19/ 4  17/ 4  17/ 4  17/ 4  15/ 4  17/ 4  14/ 4  14/ 4   9/ 4
                   MAX VALUE         271    426    599    744    744    795    935   1080   1080   1113   1442   1583   1660   1735
1971  365  100     START DATE      19/ 4  18/ 4  18/ 4  18/ 4  15/ 4  14/ 4  13/ 4  13/ 4  13/ 4  13/ 4  13/ 4  13/ 4  14/ 4  13/ 4
                   MAX VALUE         314    473    473    473    628    900    916    916    916    916    916    916   1008   1108
1972  366  100     START DATE       7/ 5   7/ 5   7/ 5   6/ 5   6/ 5   3/ 5   3/ 5   2/ 5   1/ 5  30/ 4  24/ 4  19/ 4  24/ 4  19/ 4
                   MAX VALUE         352    593    679    704    704    718    804    886    935    944   1106   1234   1333   1461
1973  364  100     START DATE      21/ 4  29/ 3  29/ 3  29/ 3  29/ 3  21/ 4  21/ 4  20/ 4  20/ 4  20/ 4  20/ 4   9/ 4  29/ 3  29/ 3
                   MAX VALUE         173    283    283    283    283    343    472    514    514    514    514    697    742    980
1974  365  100     START DATE      21/ 4  14/ 4  23/ 4  21/ 4  21/ 4  20/ 4  18/ 4  18/ 4  17/ 4  15/ 4  14/ 4  14/ 4  14/ 4  14/ 4
                   MAX VALUE         253    323    392    570    661    728    752    843    885    967   1306   1306   1718   1759
1975  365  100     START DATE      11/ 4  10/ 4  10/ 4   9/ 4  15/ 4  10/ 4   9/ 4  11/ 4  10/ 4  10/ 4   9/ 4   9/ 4   9/ 4   9/ 4
                   MAX VALUE         224    381    522    563    581    630    671    804    961   1103   1208   1208   1208   1208
1976  366  100     START DATE      11/ 4  11/ 4  10/ 4  10/ 4  10/ 4   7/ 4   6/ 4   5/ 4   5/ 4   3/ 4   6/ 4   3/ 4  30/ 3  30/ 3
                   MAX VALUE         250    452    578    629    629    770    920   1037   1080   1127   1377   1508   1630   1630
1977  365  100     START DATE       8/ 4   8/ 4  11/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4
                   MAX VALUE         244    331    356    408    669    696    696    696    732    732    732    732    734    734
1978  365  100     START DATE      29/ 4  28/ 4  28/ 4  28/ 4  27/ 4  26/ 4  26/ 4  26/ 4  26/ 4  26/ 4  26/ 4  26/ 4  10/ 4  10/ 4
                   MAX VALUE         223    401    500    630    675    688    688    688    688    688    688    690    746    746
1979  365  100     START DATE      10/ 5   9/ 5   9/ 5   9/ 5   9/ 5   9/ 5   9/ 5   9/ 5   9/ 5   9/ 5  28/ 4   9/ 5   9/ 5  28/ 4
                   MAX VALUE         320    479    482    525    525    525    525    525    525    525    628    804    899    907
1980  366  100     START DATE      28/ 3   2/ 4  31/ 3  31/ 3  31/ 3  28/ 3  28/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3
                   MAX VALUE          94    166    167    257    257    261    351    396    396    396    396    404    404    404
1981  365  100     START DATE      30/ 4   2/ 5  30/ 4  30/ 4  29/ 4  29/ 4  29/ 4  29/ 4  25/ 4  24/ 4  24/ 4  24/ 4  24/ 4  24/ 4
                   MAX VALUE         161    267    377    500    576    576    576    576    644    748    748    748    748    748
1982  364  100     START DATE      27/ 4  26/ 4  26/ 4  26/ 4  26/ 4  22/ 4  21/ 4  20/ 4  20/ 4  20/ 4  20/ 4  20/ 4  20/ 4  20/ 4
                   MAX VALUE         253    421    421    421    441    488    636    759    759    759    791    855   1105   1105
1983  365  100     START DATE      26/ 9  22/ 4  21/ 4  20/ 4  20/ 4  18/ 4  17/ 4  17/ 4  17/ 4  15/ 4  15/ 4   5/ 4  17/ 4  15/ 4
                   MAX VALUE         201    239    336    465    519    572    678    732    732    769    866    913   1054   1095
1984  366  100     START DATE      31/ 3  30/ 3  29/ 3  29/ 3  28/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3  23/ 3  23/ 3  23/ 3  23/ 3
                   MAX VALUE         233    377    606    694    720    747    747    760    760    760    771    771    771    771
1985  181   49  ** START DATE       1/ 5  30/ 4  30/ 4  30/ 4  27/ 4  26/ 4  26/ 4  26/ 4  26/ 4  26/ 4  17/ 4  12/ 4   8/ 4   8/ 4
                   MAX VALUE         210    283    355    355    384    490    562    562    562    562    716    797   1077   1077
****************************************************************************************************************

                                   1 DAY  2 DAY  3 DAY  4 DAY  5 DAY  6 DAY  7 DAY  8 DAY  9 DAY 10 DAY 15 DAY 20 DAY 25 DAY 30 DAY

             MEAN EXTREME(MM)       30.5   47.9   59.9   67.3   72.7   77.1   82.7   88.3   92.4   95.5  106.8  115.7  121.7  125.9
             STD  DEV (MM)          15.7   23.9   32.3   33.5   34.3   35.7   35.9   37.7   39.0   39.9   45.8   49.6   50.9   52.4
             YEARS ANALYSED         41.0   41.0   41.0   41.0   41.0   41.0   41.0   41.0   41.0   41.0   41.0   41.0   41.0   41.0
```

Table 3. Snowmelt Model 3 Calculations for Hay River, N.W.T.

Table 4. Snowmelt Return Period Values for Hay River, N.W.T.

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                                         ATMOSPHERIC ENVIRONMENT SERVICE
                                 RAIN+SNOWMELT INTENSITY, DURATION, FREQUENCY VALUES
                              PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE
************************************************************************************************************************

STATION : HAY RIVER, N.W T     (SNOWMELT MODEL 3)                                                  STATION NUMBER  2202400

CRITICAL PERIOD :  1ST OF MONTH 10 TO THE END OF MONTH 5                                        NOTE : MODIFIED GUMBEL 12/82
                            RAIN+SNOWMELT RETURN PERIOD VALUES  (MM)         WITH 50% CONFIDENCE LIMITS
************************************************************************************************************************

RETURN PERIOD
YEARS                         1 DAY            2 DAY            3 DAY            4 DAY            5 DAY

  2                     27.90+/- 1.51    43.94+/- 2.31    54.59+/- 3.12    61.84+/- 3.23    67.03+/- 3.32
  5                     41.73+/- 2.55    65.07+/- 3.89    83.11+/- 5.25    91.39+/- 5.44    97.34+/- 5.58
 10                     50.91+/- 3.44    79.10+/- 5.26   102.03+/- 7.10   110.99+/- 7.35   117.45+/- 7.55
 25                     62.48+/- 4.64    96.78+/- 7.09   125.90+/- 9.57   135.72+/- 9.91   142.82+/-10.17
 50                     71.07+/- 5.55   109.90+/- 8.48   143.60+/-11.45   154.05+/-11.86   161.63+/-12.17
100                     79.60+/- 6.47   122.94+/- 9.89   161.20+/-13.34   172.29+/-13.82   180.34+/-14.18
RETURN PERIOD
YEARS                         6 DAY            7 DAY            8 DAY            9 DAY           10 DAY

  2                     71.24+/- 3.45    76.85+/- 3.46    82.12+/- 3.64    86.00+/- 3.76    88.91+/- 3.86
  5                    102.77+/- 5.81   108.51+/- 5.83   115.42+/- 6.14   120.40+/- 6.34   124.18+/- 6.50
 10                    123.70+/- 7.85   129.52+/- 7.88   137.52+/- 8.29   143.22+/- 8.56   147.58+/- 8.78
 25                    150.08+/-10.58   156.02+/-10.62   165.39+/-11.10   172.01+/-11.54   177.10+/-11.84
 50                    169.65+/-12.66   175.66+/-12.71   186.06+/-13.37   193.36+/-13.81   198.99+/-14.16
100                    189.11+/-14.75   195.20+/-14.81   206.61+/-15.58   214.59+/-16.09   220.75+/-16.58
RETURN PERIOD
YEARS                        15 DAY           20 DAY           25 DAY           30 DAY

  2                     99.33+/- 4.42   107.60+/- 4.79   113.37+/- 4.92   117.35+/- 5.06
  5                    139.74+/- 7.44   151.39+/- 8.07   158.35+/- 8.29   163.59+/- 8.52
 10                    166.56+/-10.06   180.44+/-10.90   188.20+/-11.20   194.29+/-11.51
 25                    200.38+/-13.56   217.09+/-14.69   225.84+/-15.09   232.99+/-15.52
 50                    225.45+/-16.22   244.26+/-17.58   253.75+/-18.06   261.70+/-18.57
100                    250.39+/-18.90   271.28+/-20.48   281.52+/-21.04   290.24+/-21.64
** WARNING ** : 100 YEAR VALUES IN  1961 BASED ON  1 DAYS ACCUMULATION
** WARNING ** : 100 YEAR VALUES IN  1961 BASED ON  2 DaYS ACCUMULATION
** WARNING ** : 100 YEAR VALUES IN  1961 BASED ON  3 DAYS ACCUMULATION
** WARNING ** : 100 YEAR VALUES IN  1961 BASED ON  4 DAYS ACCUMULATION
** WARNING ** : 100 YEAR VALUES IN  1961 BASED ON  5 DAYS ACCUMULATION
** WARNING ** : 100 YEAR VALUES IN  1961 BASED ON  6 DAYS ACCUMULATION
** WARNING ** : 100 YEAR VALUES IN  1966 BASED ON  6 DAYS ACCUMULATION
** WARNING ** : 100 YEAR VALUES IN  1961 BASED ON  7 DAYS ACCUMULATION
```

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                                   ATMOSPHERIC ENVIRONMENT SERVICE
                          RAIN+SNOWMELT INTENSITY, DURATION, FREQUENCY VALUES
**************************PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE***************************

STATION : HIGH LEVEL, ALTA.    (SNOWMELT MODEL 3)
CRITICAL PERIOD :  1ST OF MONTH 10 TO THE END OF MONTH 5                                        STATION NUMBER  3073146
                                                                                        NOTE : MODIFIED GUMBEL 12/82
      TOTAL  %
YEARS DAYS VALID FLAG                1 DAY  2 DAY  3 DAY  4 DAY  5 DAY  6 DAY  7 DAY  8 DAY  9 DAY 10 DAY 15 DAY 20 DAY 25 DAY 30 DAY

1970    92   25   **
1971   365  100.       START DATE    14/ 4  14/ 4  13/ 4  14/ 4  13/ 4  13/ 4  13/ 4  13/ 4  13/ 4   6/ 4   4/ 4   4/ 4   4/ 4   4/ 4
                        MAX VALUE      224    379    454    512    587    616    616    616    616    663    942    942    942    942
1972   366  100.       START DATE    20/ 4  27/ 4  20/ 4  26/ 4  25/ 4  24/ 4  24/ 4  24/ 4  24/ 4  24/ 4  19/ 4  14/ 4  14/ 4  14/ 4
                        MAX VALUE      774   1031   1108   1343   1438   1579   1615   1615   1615   1615   1708   1820   1820   1820
1973   365  100.       START DATE    10/ 4  10/ 4   9/ 4   9/ 4   8/ 4   8/ 4   9/ 4   9/ 4   5/ 4   9/ 4  29/ 3  31/ 3  28/ 3  28/ 3
                        MAX VALUE      241    395    546    634    646    646    730    772    821    954   1178   1473   1677   1677
1974   365  100.       START DATE    14/ 4  14/ 4  13/ 4  14/ 4  14/ 4  13/ 4  13/ 4  14/ 4  13/ 4  12/ 4   7/ 4   7/ 4   7/ 4   7/ 4
                        MAX VALUE      224    423    598    764    964   1139   1289   1438   1613   1721   2293   2307   2312   2370
1975   365  100.       START DATE    12/ 4  11/ 4  10/ 4  10/ 4  11/ 4  11/ 4  11/ 4  10/ 4   5/ 4   8/ 4   8/ 4   8/ 4   8/ 4   8/ 4
                        MAX VALUE      424    623    707    789    871    979   1094   1178   1244   1251   1251   1251   1251   1251
1976   366  100.       START DATE     7/ 4   7/ 4   6/ 4   6/ 4   6/ 4   5/ 4   4/ 4   3/ 4   2/ 4   2/ 4  28/ 3  27/ 3  27/ 3  27/ 3
                        MAX VALUE      281    488    696    787    953    994   1103   1212   1245   1275   1491   1507   1507   1507
1977   365  100.       START DATE     5/ 4   5/ 4   4/ 4   4/ 4   4/ 4   4/ 4   4/ 4   4/ 4  30/ 3  30/ 3  30/ 3  30/ 3  30/ 3   4/ 4
                        MAX VALUE      253    333    429    461    461    461    461    461    463    463    463    463    463    548
1978   365  100.       START DATE    22/ 5  22/ 5   8/ 4   8/ 4  16/ 4  16/ 4  16/ 4  16/ 4   4/ 4   8/ 4   8/ 4   8/ 4  28/ 3  28/ 3
                        MAX VALUE      146    208    354    441    501    501    501    501    530    641    942    942    984    984
1979   365  100.       START DATE    27/ 5   3/ 5  27/ 4  26/ 4  25/ 4  25/ 4  23/ 4  22/ 4  22/ 4  22/ 4  23/ 4  22/ 4  22/ 4  22/ 4
                        MAX VALUE      337    342    462    586    709    735    797    875    901    901   1116   1282   1282   1282
1980   366  100.       START DATE    23/ 1  28/ 3  27/ 3  27/ 3  29/ 3  28/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3  27/ 3
                        MAX VALUE      125    172    242    282    336    415    487    487    487    487    487    487    487    487
1981   365  100.       START DATE     9/10  21/ 4  20/ 4  20/ 4  19/ 4  20/ 4  23/ 4  19/ 4  19/ 4  19/ 4  19/ 4  19/ 4   2/ 4   2/ 4
                        MAX VALUE      231    395    530    598    631    663    737    770    770    770    770    770    883    883
1982   365  100.       START DATE    22/ 4  22/ 4  22/ 4  19/ 4  18/ 4  17/ 4  17/ 4  17/ 4  13/ 4  13/ 4   8/ 4   8/ 4  12/ 4   8/ 4
                        MAX VALUE      306    358    433    487    491    551    551    551    623    698    781    781    883    914
1983   364  99.7       START DATE    21/ 4  20/ 4  19/ 4  18/ 4  17/ 4  16/ 4  15/ 4  14/ 4  13/ 4  13/ 4  13/ 4   5/ 4   5/ 4   5/ 4
                        MAX VALUE      434    585    706    873   1071   1213   1330   1431   1486   1496   1496   1740   1740   1750
1984   366  100.       START DATE     3/ 4   2/ 4   1/ 4  31/ 3  31/ 3  29/ 3  29/ 3  29/ 3  27/ 3  27/ 3  24/ 3  24/ 3  24/ 3  24/ 3
                        MAX VALUE      133    247    373    485    595    687    797    797    855    855    877    877    877    877
1985   181   49   **   START DATE    13/ 4  12/ 4  12/ 4  12/ 4   9/ 4   8/ 4   8/ 4  12/ 4  12/ 4  12/ 4   8/ 4   1/ 4   1/ 4   1/ 4
                        MAX VALUE      263    436    506    506    547    706    776    825    893    893   1163   1232   1252   1252
*****************************************************************************************************************************

                                     1 DAY  2 DAY  3 DAY  4 DAY  5 DAY  6 DAY  7 DAY  8 DAY  9 DAY 10 DAY 15 DAY 20 DAY 25 DAY 30 DAY

                MEAN EXTREME(MM)      28.3   43.2   55.2   64.4   73.6   80.6   86.3   90.7   94.8   98.5  113.4  118.8  122.2  123.5
                STD. DEV.(MM)         17.4   21.0   23.0   26.0   30.5   33.6   36.0   39.5   41.6   41.6   50.5   53.5   53.4   53.4
                YEARS ANALYZED        14.0   14.0   14.0   14.0   14.0   14.0   14.0   14.0   14.0   14.0   14.0   14.0   14.0   14.0

NOTE            **  VALUE IN FLAG INDICATES YEAR NOT INCLUDED IN ANALYSIS BASED ON % DAYS OPERATIONAL ( <90.0% )
** WARNING :  RETURN PERIOD RAINFALL VALUE IS BASED ON LESS THAN 15.00 YEARS DATA
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Table 5. Snowmelt Model 3 Calculations for High Level, Alberta

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                                   ATMOSPHERIC ENVIRONMENT SERVICE
                          RAIN+SNOWMELT INTENSITY, DURATION, FREQUENCY VALUES
**************************PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE***************************

STATION : HIGH LEVEL, ALTA.    (SNOWMELT MODEL 3)
                                                                                             STATION NUMBER  3073146
CRITICAL PERIOD :  1ST OF MONTH 10 TO THE END OF MONTH 5
                                                                                        NOTE : MODIFIED GUMBEL 12/82
********************RAIN+SNOWMELT RETURN PERIOD VALUES  (MM)..........WITH 95% CONFIDENCE LIMITS*************************
RETURN PERIOD
YEARS
                        1 DAY            2 DAY            3 DAY            4 DAY            5 DAY

  2               25.49+/- 2.85    39.82+/- 3.48    51.39+/- 3.81    60.11+/- 4.33    68.60+/- 5.04
  5               40.59+/- 4.76    58.37+/- 5.85    71.73+/- 6.41    83.05+/- 7.23    95.52+/- 8.49
 10               50.62+/- 6.44    70.69+/- 7.91    85.23+/- 8.66    98.27+/- 9.77   113.38+/-11.47
 25               63.26+/- 8.68    86.24+/-10.67   102.25+/-11.68   117.46+/-13.17   135.93+/-15.46
 50               72.64+/-10.38    97.75+/-12.76   114.88+/-13.96   131.70+/-15.76   152.61+/-18.49
100               81.96+/-11.99   109.22+/-14.67   127.43+/-16.26   145.85+/-18.36   169.22+/-21.55
RETURN PERIOD
YEARS
                        6 DAY            7 DAY            8 DAY            9 DAY           10 DAY

  2               74.49+/- 5.55    80.37+/- 5.95    84.27+/- 6.53    87.96+/- 6.68    91.68+/- 6.88
  5              104.13+/- 9.34   112.13+/-10.02   119.13+/-10.99   124.09+/-11.56   128.42+/-11.58
 10              123.80+/-12.63   133.23+/-13.54   142.26+/-14.85   149.06+/-15.65   152.80+/-15.65
 25              148.61+/-17.02   159.63+/-18.25   171.43+/-20.02   179.80+/-21.10   183.55+/-21.10
 50              167.01+/-20.27   179.35+/-21.63   193.27+/-23.95   202.62+/-25.24   206.35+/-25.25
100              185.29+/-23.73   199.16+/-25.44   214.58+/-27.91   225.27+/-29.41   229.02+/-29.41
RETURN PERIOD
YEARS
                       15 DAY           20 DAY           25 DAY           30 DAY

  2              105.12+/- 9.35   110.07+/- 8.85   113.44+/- 8.83   114.76+/- 8.82
  5              149.68+/-14.05   157.34+/-14.93   160.59+/-14.87   161.89+/-14.86
 10              179.25+/-18.99   188.71+/-20.14   191.89+/-20.09   193.16+/-20.18
 25              216.55+/-25.59   228.27+/-27.15   231.35+/-27.08   232.60+/-27.07
 50              244.21+/-30.62   257.61+/-32.48   260.61+/-32.43   261.85+/-32.38
100              271.71+/-35.66   285.78+/-37.84   289.71+/-37.75   290.94+/-37.73
```

Table 6. Snowmelt Return Period Values for High Level, Alberta

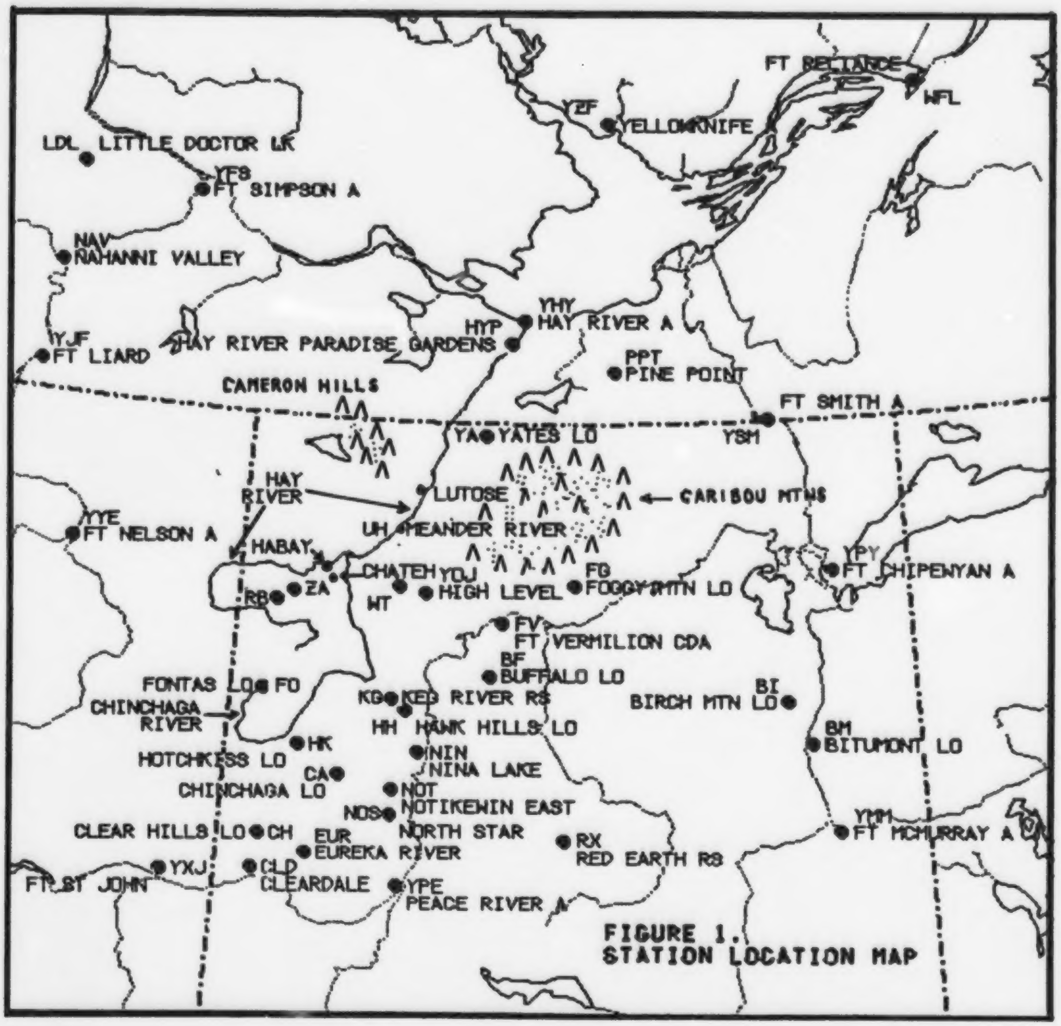
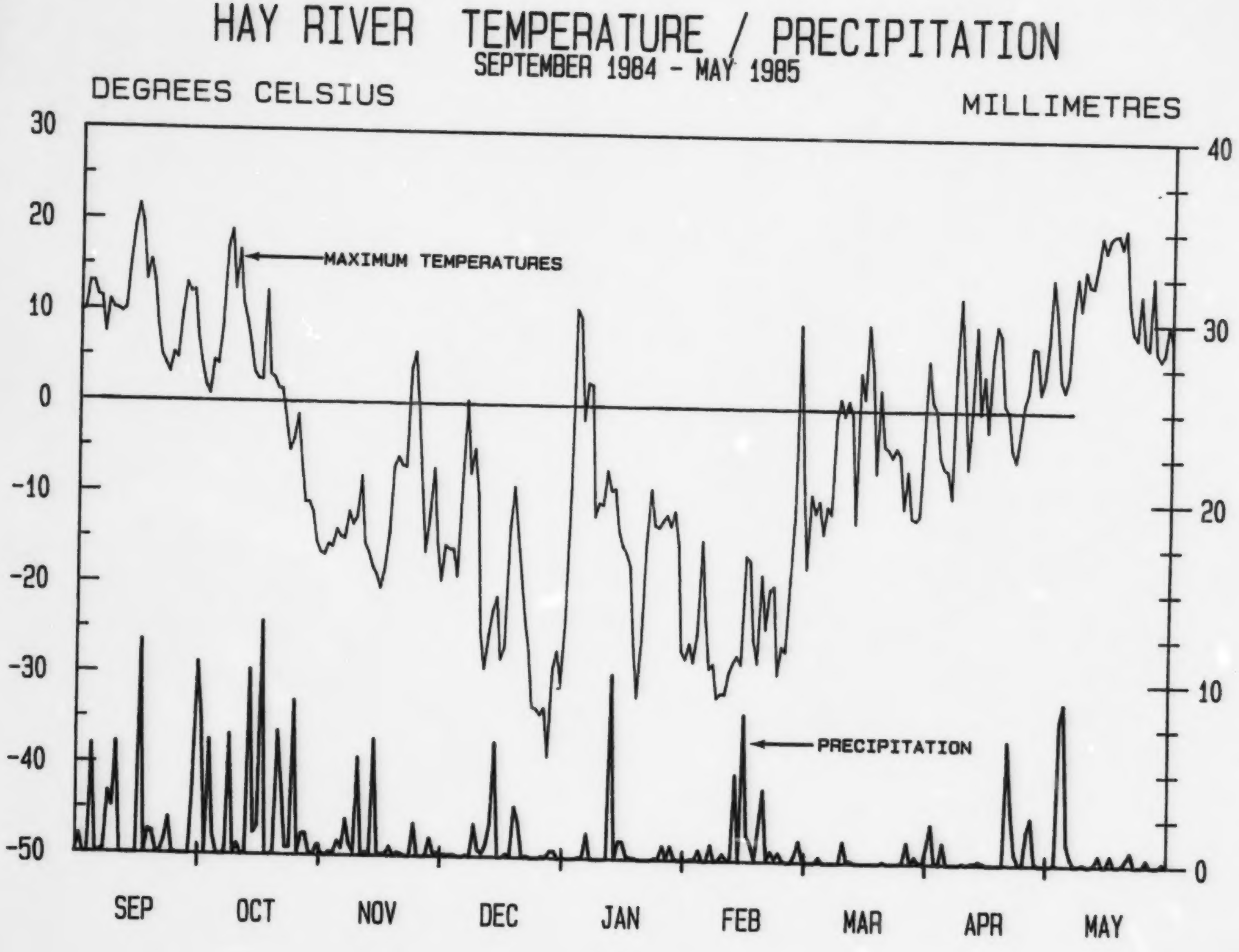

FT RELIANCE
WFL
ZF
YELLOWKNIFE
LDL LITTLE DOCTOR LK
YFS
FT SIMPSON A
NAV
NAHANNI VALLEY
YHY
HAY RIVER A
HYP
YJF
FT LIARD
HAY RIVER PARADISE GARDENS
PPT
PINE POINT
CAMERON HILLS
FT SMITH A
YSM
YA YATES LO
HAY RIVER
LUTOSE
CARIBOU MTNS
YYE
FT NELSON A
UH MEANDER RIVER
HABAY
CHATEH
YOJ
FG
YPY
FT CHIPEWYAN A
RB
ZA
WT
HIGH LEVEL
FOGGY MTN LO
FV
FT VERMILION CDA
BF
BUFFALO LO
FONTAS LO FO
CHINCHAGA RIVER
KG KEG RIVER RS
BI
BIRCH MTN LO
HH HAWK HILLS LO
BM
BITUMONT LO
HK
HOTCHKISS LO
NIN
NINA LAKE
CA
CHINCHAGA LO
NOT
NOS NOTIKEWIN EAST
NORTH STAR
YMM
FT MCMURRAY A
CLEAR HILLS LO CH
EUR
EUREKA RIVER
RX
RED EARTH RS
YXJ
FT ST JOHN
CLD
CLEARDALE
YPE
PEACE RIVER A

FIGURE 1.
STATION LOCATION MAP



HAY RIVER TEMPERATURE / PRECIPITATION
SEPTEMBER 1984 - MAY 1985

FIGURE 2

HIGH LEVEL TEMPERATURE / PRECIPITATION
SEPTEMBER 1984 - MAY 1985

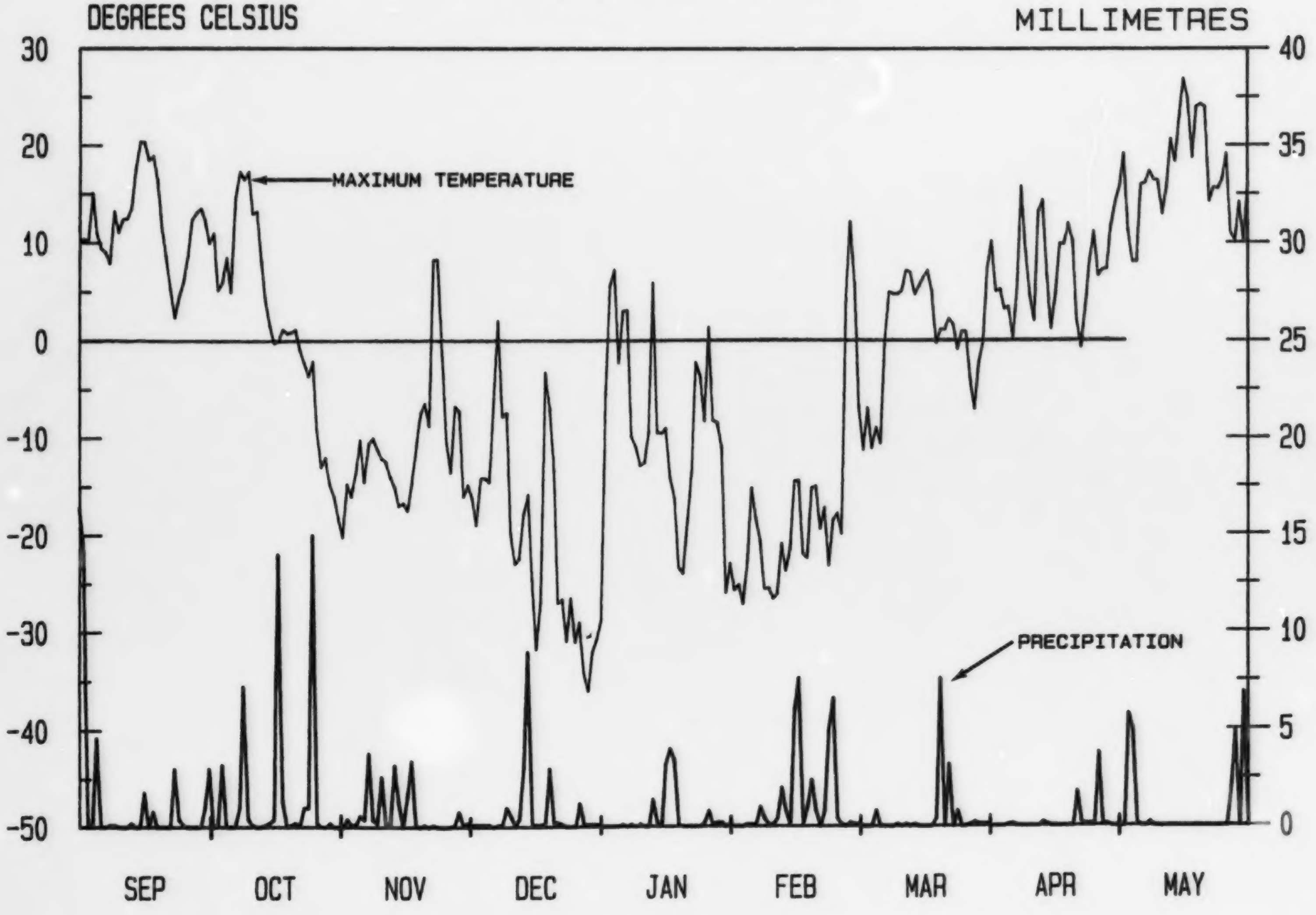


FIGURE 3

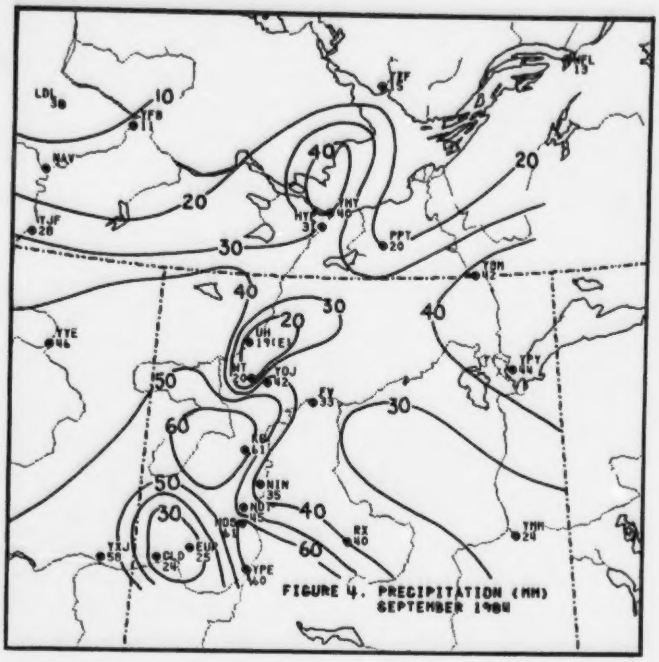

10
20
30
40
50
60
30
20
40
30
60
50
30
40
60

FIGURE 4. PRECIPITATION (MM)
SEPTEMBER 1984

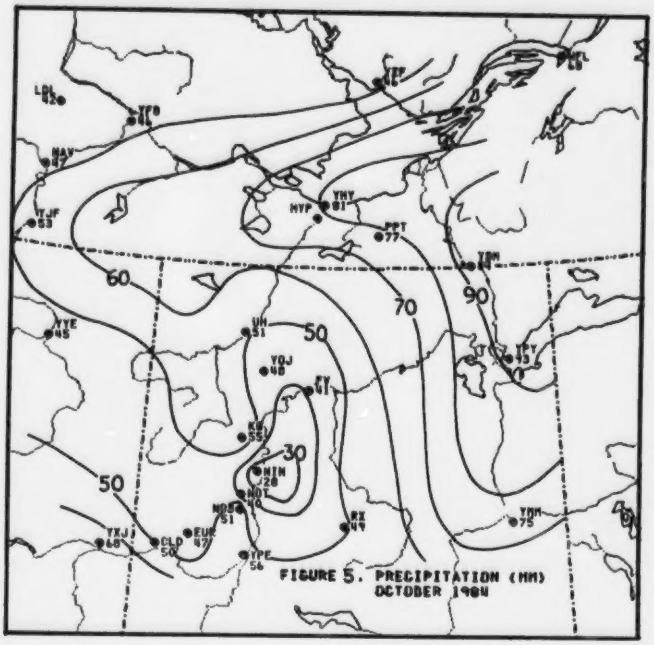

60
50
70
90
50
30

FIGURE 5. PRECIPITATION (MM)
OCTOBER 1984

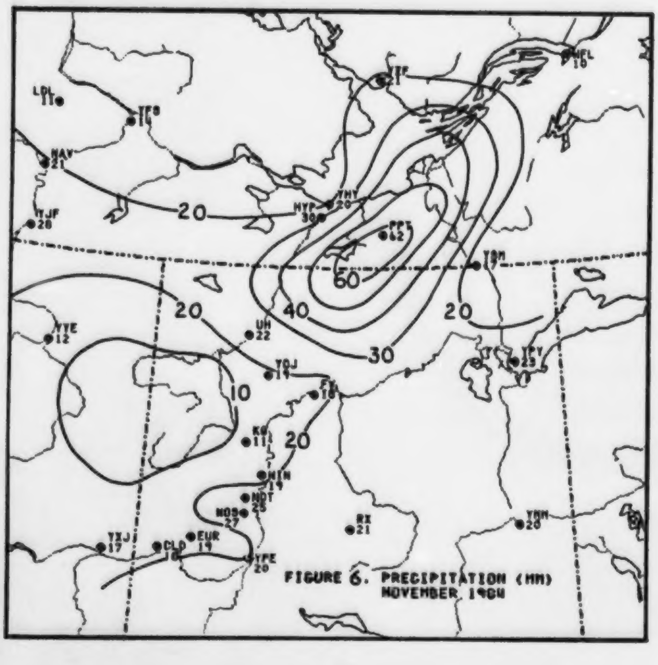

20
20
60
40
30
20
10
20

FIGURE 6. PRECIPITATION (MM)
NOVEMBER 1984

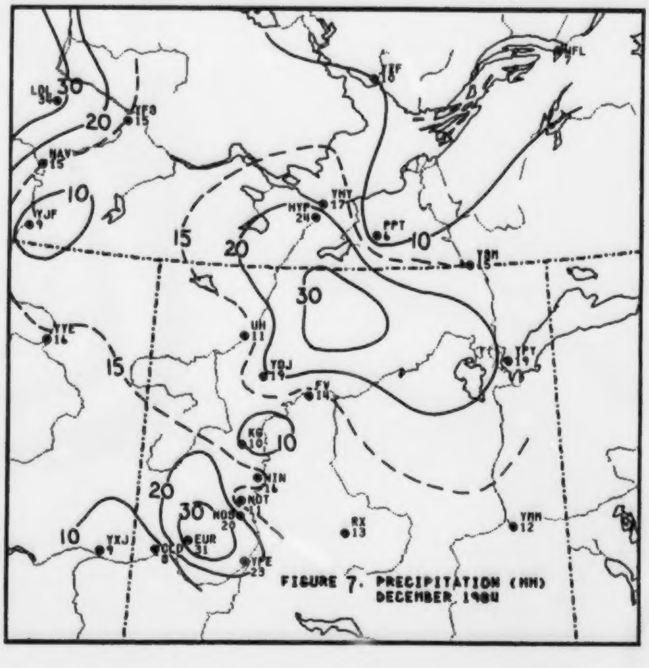
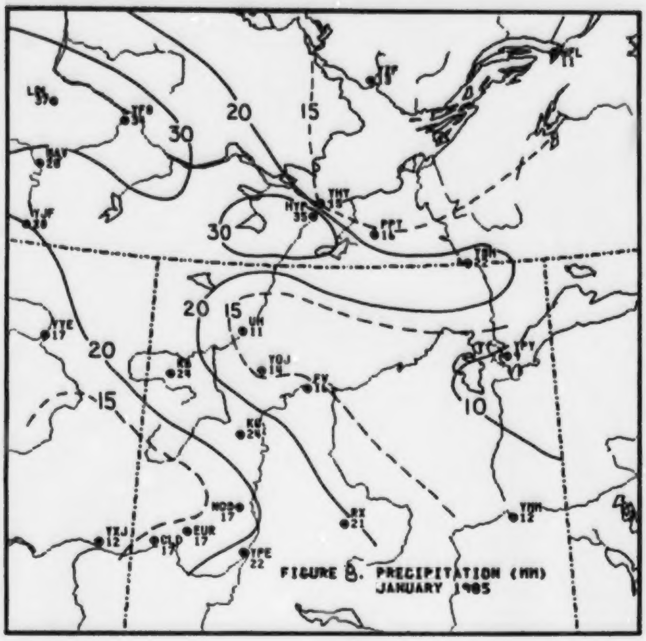
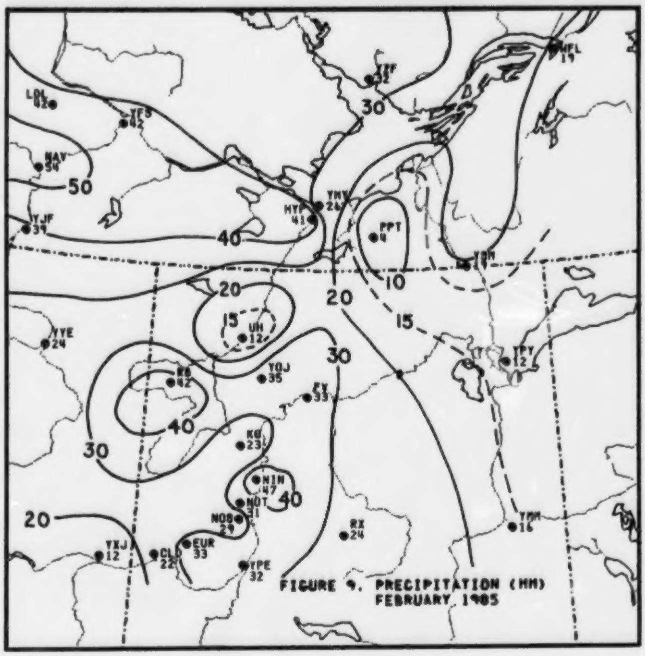

30
20
10
15
20
10
30
15
10
20
30
10

FIGURE 7. PRECIPITATION (MM)
DECEMBER 1984



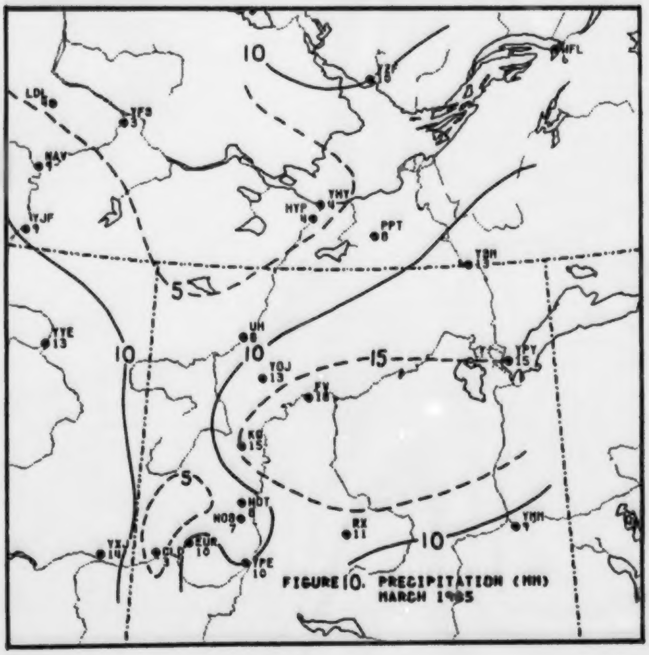
LDL
NAV
YJF
HYP
YMY
PPT
YBM
YYE
UH
YOJ
FV
KG
NOS
EUR
CLD
YXJ
YPE
RX
YMM
HFL
30
20
15
30
20
15
20
15
10

FIGURE 8. PRECIPITATION (MM) JANUARY 1985



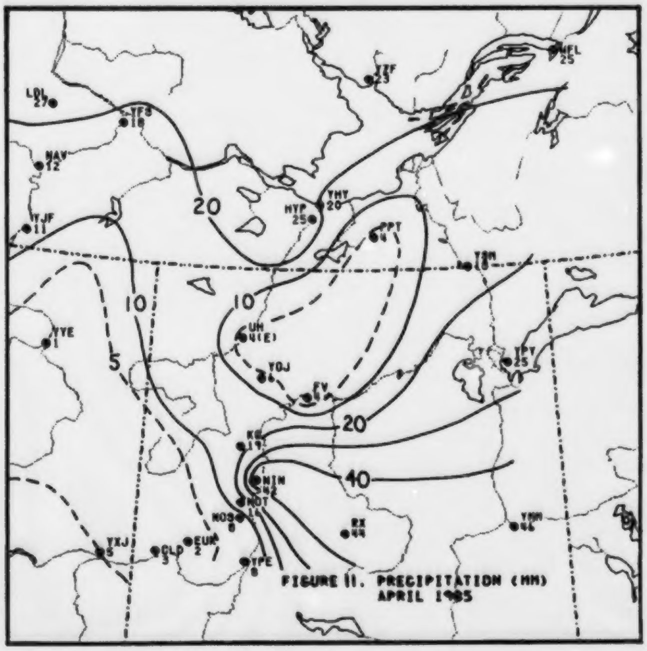
LDL
NAV
YJF
HYP
YMY
PPT
YBM
YYE
UH
YOJ
FV
KG
NIN
NOT
NOS
EUR
CLD
YXJ
YPE
RX
YMM
HFL
50
40
30
20
15
30
40
30
20
40
20
10
15

FIGURE 9. PRECIPITATION (MM) FEBRUARY 1985



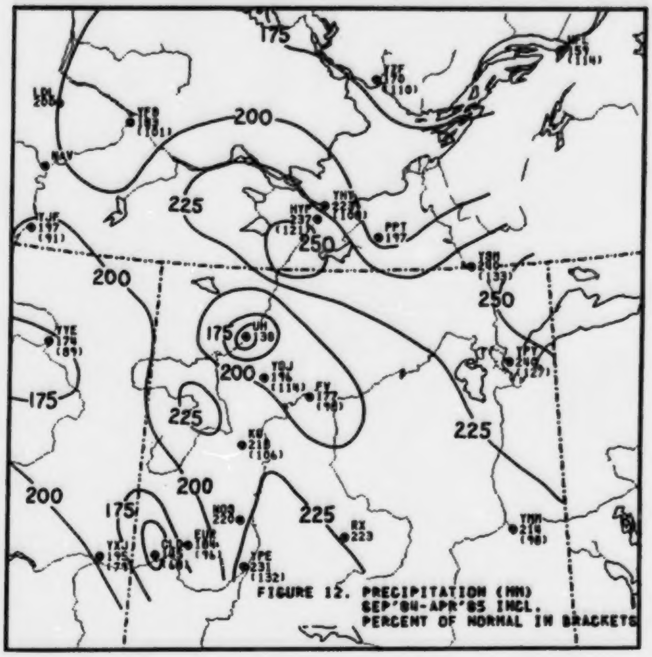
LDL
NAV
YJF
HYP
YMY
PPT
YBM
YYE
UH
YOJ
FV
KG
NOT
NOS
EUR
CLD
YXJ
YPE
RX
YMM
HFL
10
5
10
10
15
5
10

FIGURE 10. PRECIPITATION (MM) MARCH 1985



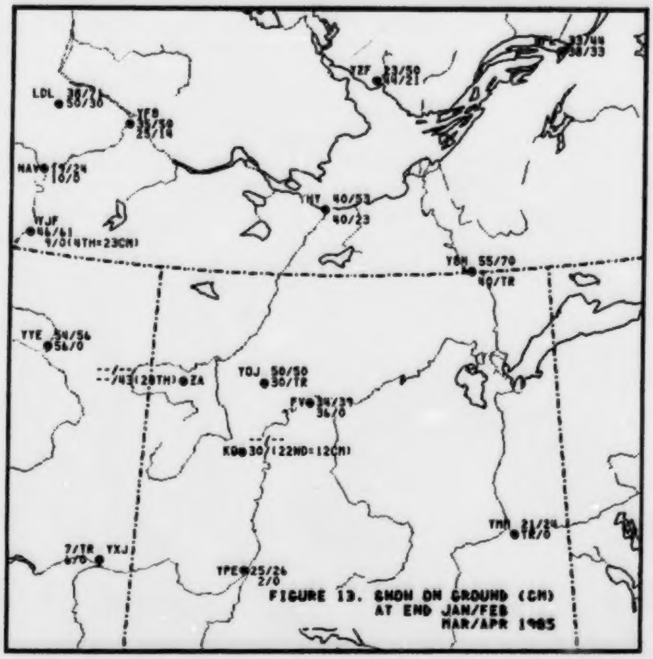
LDL
NAV
YJF
HYP
YMY
PPT
YBM
YYE
UH
YOJ
FV
KG
NIN
NOT
NOS
EUR
CLD
YXJ
YPE
RX
YMM
HFL
20
10
10
5
20
40

FIGURE 11. PRECIPITATION (MM) APRIL 1985



175
200
225
250
175
200
225
250
200
175
225
200
200
175
225
225
LDL 200
NAV
YJF 197 (91)
YYE 174 (89)
YZF 175 (110)
HYF 237 (121)
PPT 197
YSM 280 (133)
UH 130
YQJ 196 (114)
FY 177 (96)
KQ 218 (106)
HOB 220
EUR 184 (96)
YXJ 195 (79)
YPE 231 (132)
RX 223
YMM 216 (98)
YPY 240 (127)

FIGURE 12. PRECIPITATION (MM)
SEP'84-APR'85 INCL.
PERCENT OF NORMAL IN BRACKETS



LDL 30/71 50/30
23/14
NAV 19/24 10/0
YJF 46/61 9/0(4TH=23CM)
YZF 23/50 44/21
33/44 38/33
YHY 40/53 40/23
YSM 55/70 40/TR
YYE 34/56 56/0
--/-- --/43(28TH) ZA
YQJ 50/50 30/TR
FV 34/39 36/0
--/-- KQ 30/(22ND=12CM)
YMM 21/26 TR/0
7/TR YXJ 6/0
YPE 25/26 2/0

FIGURE 13. SNOW ON GROUND (CM)
AT END JAN/FEB
MAR/APR 1985

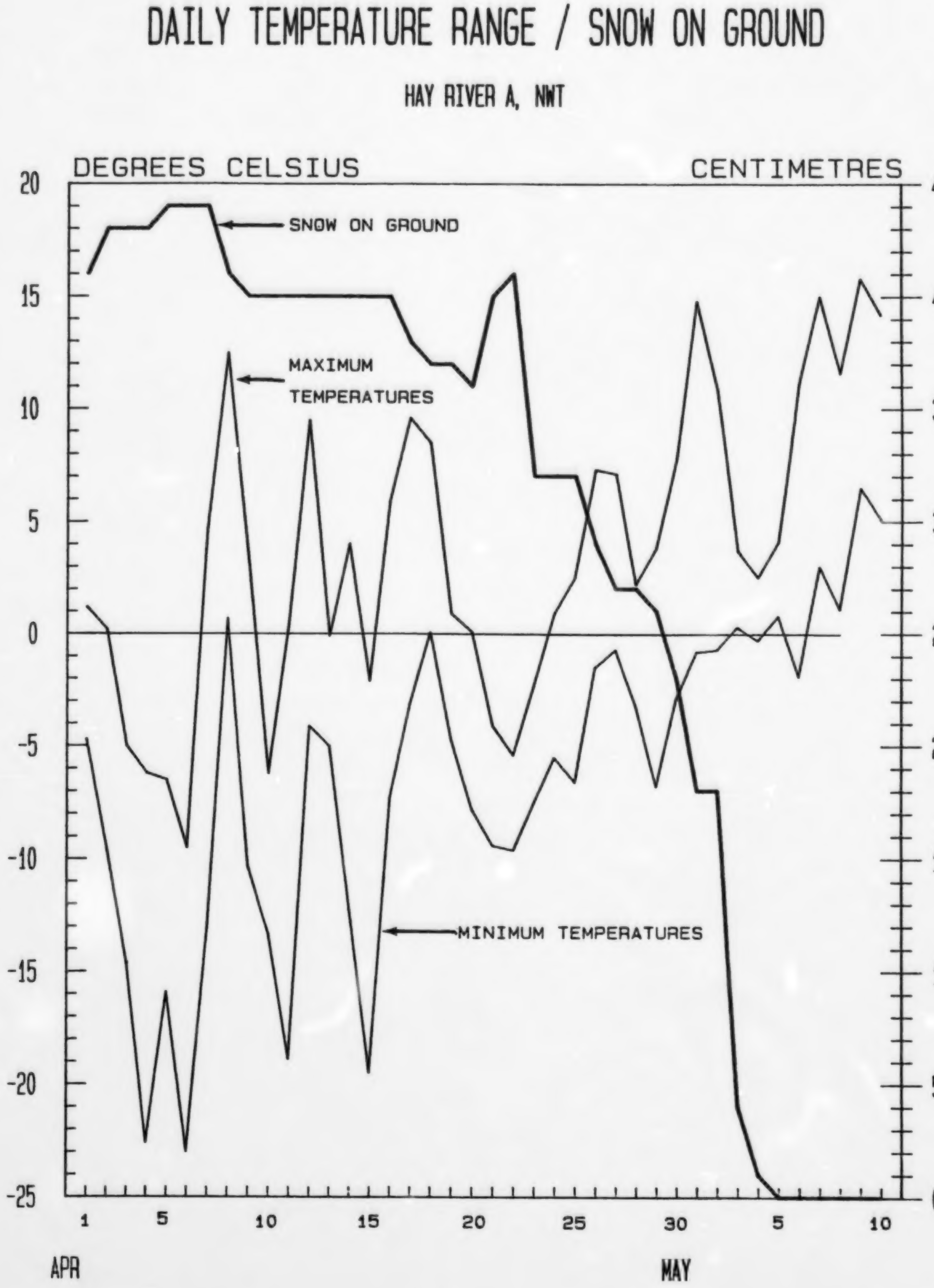
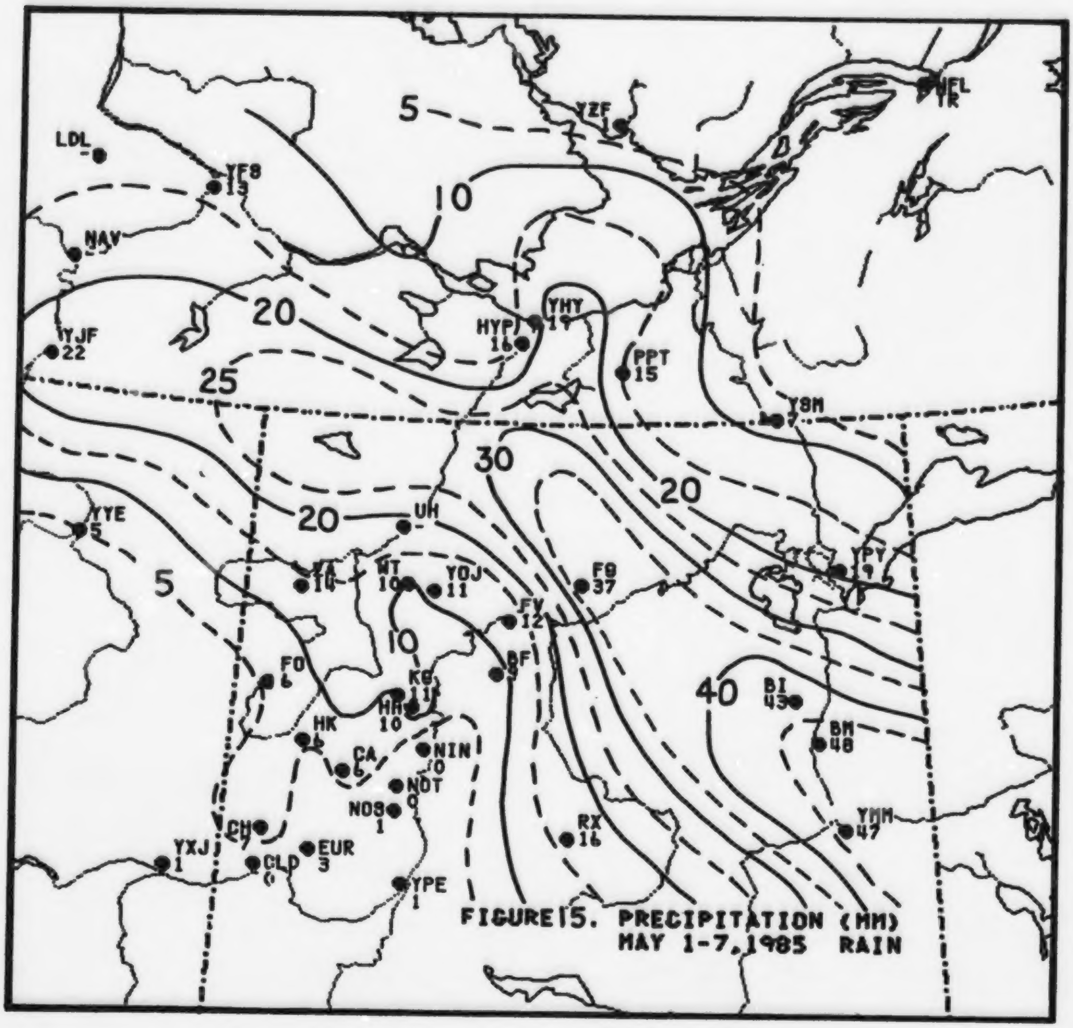

DAILY TEMPERATURE RANGE / SNOW ON GROUND
HAY RIVER A, NWT
DEGREES CELSIUS
CENTIMETRES
20
15
10
5
0
-5
-10
-15
-20
-25
45
40
35
30
25
20
15
10
5
0
SNOW ON GROUND
MAXIMUM TEMPERATURES
MINIMUM TEMPERATURES
1
5
10
15
20
25
30
5
10
APR
MAY

FIGURE 14



5
10
20
25
30
20
20
5
10
40
LDL
YF8
13
NAV
YJF
22
YZF
1
HFL
YHY
HYP
16
PPT
15
Y8M
7
YYE
5
UH
WT
10
YOJ
11
F8
37
FY
12
YPY
9
FO
6
K8
HR
10
BF
HK
6
CA
6
NIN
0
NOT
0
NOS
1
CH
BI
43
BM
48
YMM
47
RX
16
YXJ
1
CLD
EUR
3
YPE
1

FIGURE 15. PRECIPITATION (MM)
MAY 1-7, 1985 RAIN

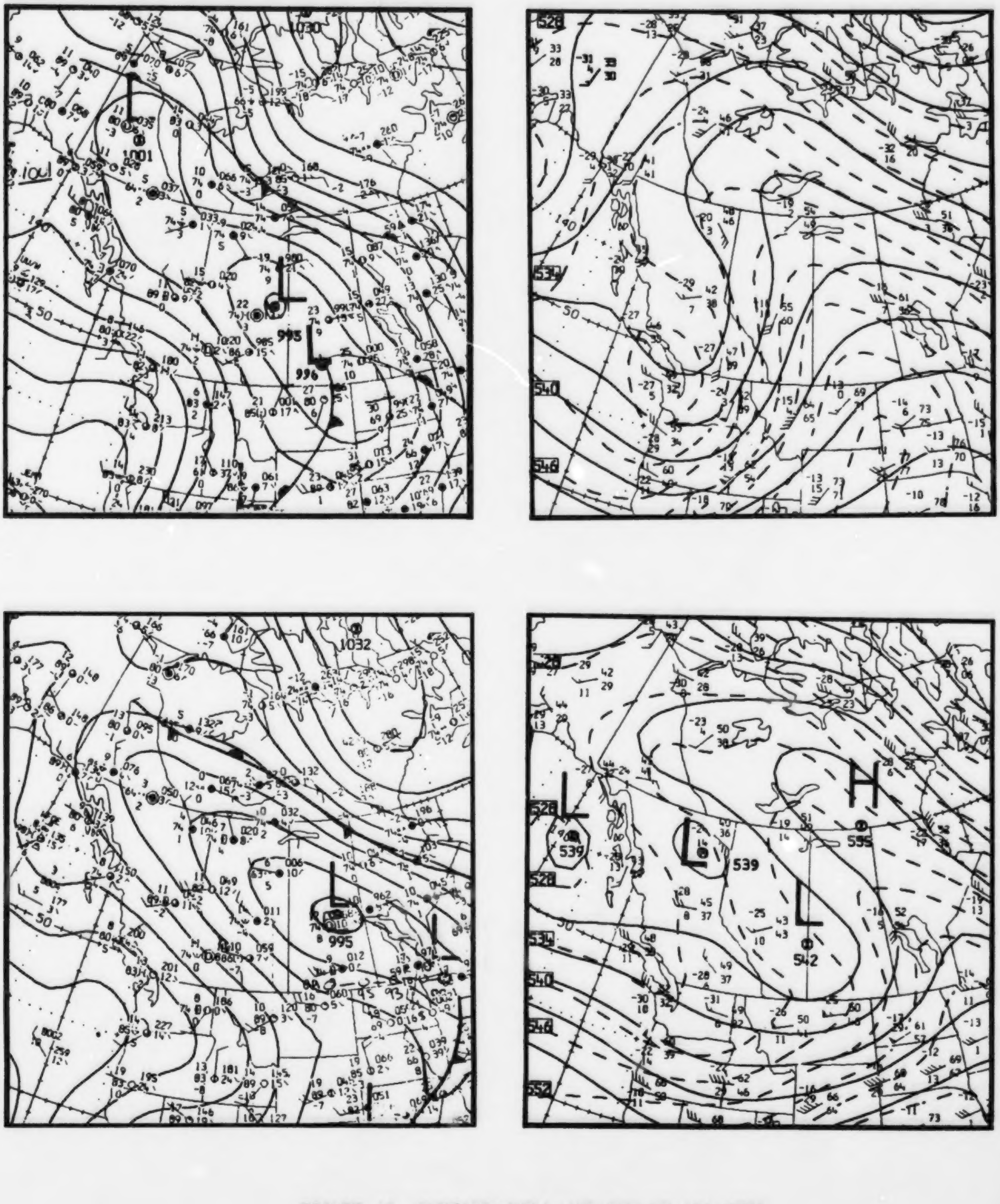

1001
1030
995
996
528
534
540
546
1032
995
539
539
535
542
552
H
L

FIGURE 18. SURFACE (MSL) AND 500-MB ANALYSES
TOP - 0000 GMT 4 MAY 1985
BOTTOM - 0000 GMT 5 MAY 1985

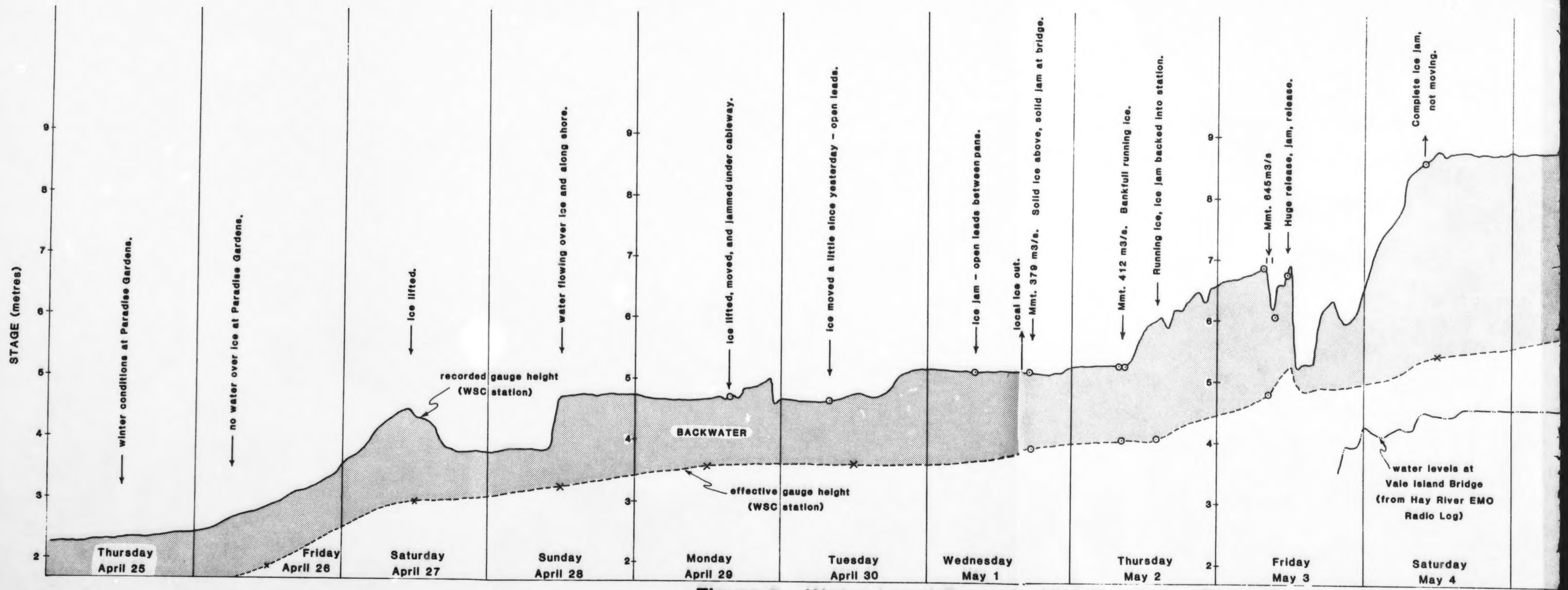


Figure 8. Water Level Record, Vicinity of Hay River, Spring, 1985

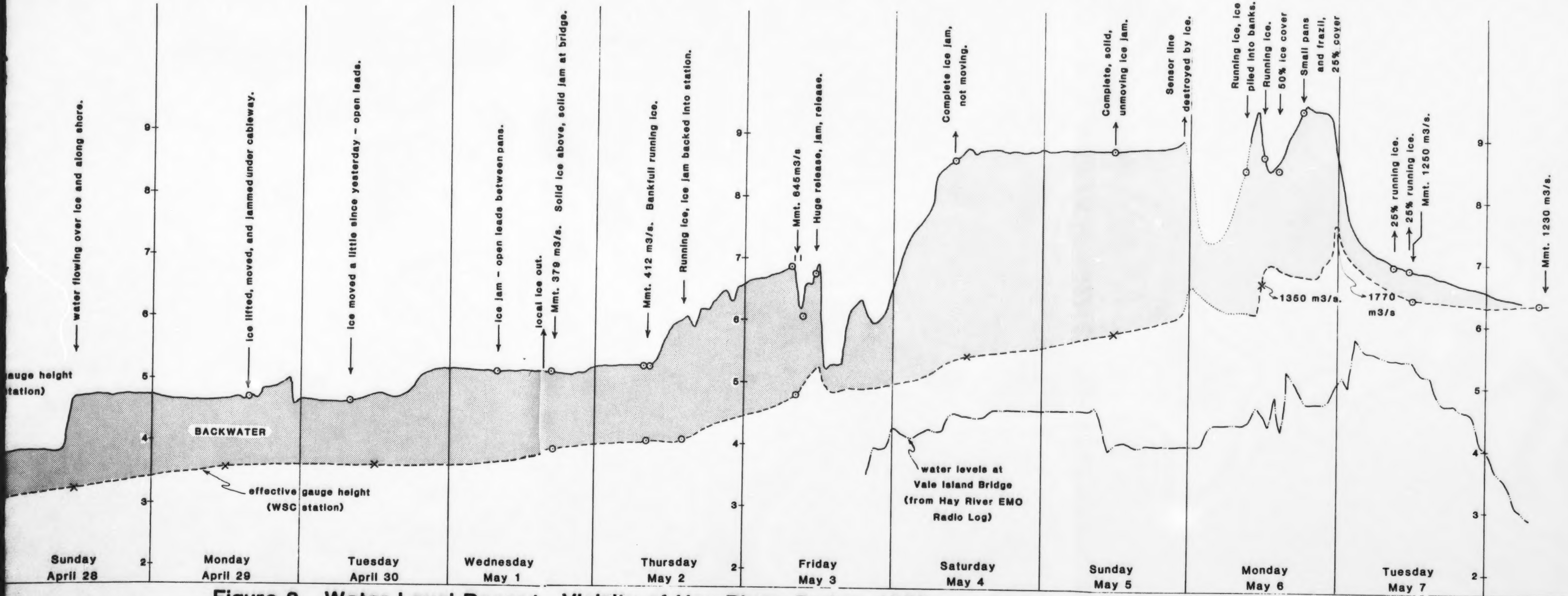
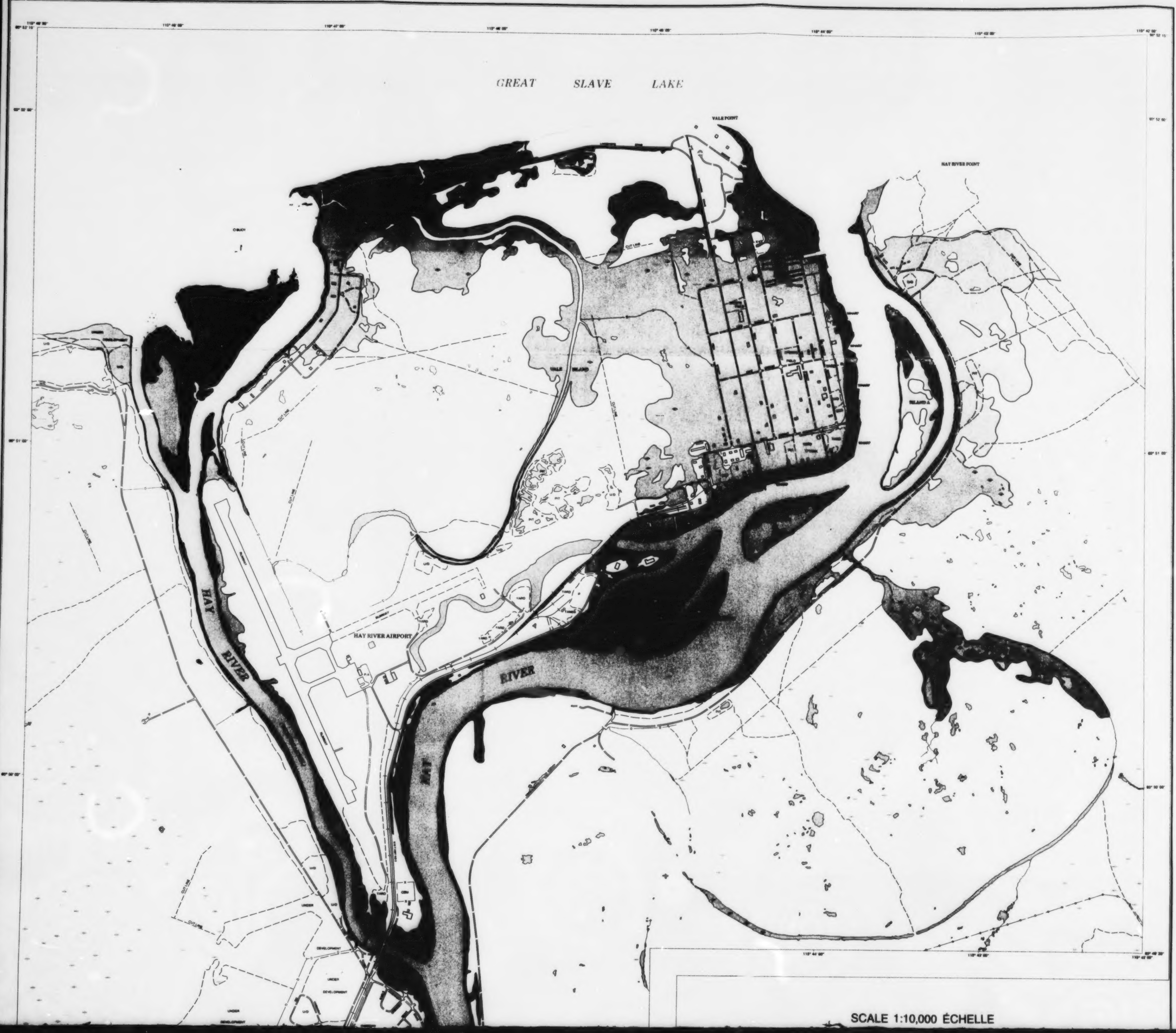


Figure 8. Water Level Record, Vicinity of Hay River, Spring, 1985



SCALE 1:10,000 ÉCHELLE

Environment Canada
Environnement Canada

Indian and Northern AffairsCanada
Affaires indiennes et du Nord Canada

Northwest Territories Canada
Territoires du Nord-Ouest Canada

FLOOD RISK MAP
RÉGION DE HAY RIVER AREA
NORTHWEST TERRITORIES
TERRITOIRES DU NORD-OUEST
CARTE DE RISQUE D'INONDATION

UNDER THE CANADA - NORTHWEST TERRITORIES AGREEMENT RESPECTING FLOOD DAMAGE REDUCTION AND FLOOD RISK MAPPING, THE FLOOD RISK AREAS AND FLOODWAY DEPICTED ON THIS MAP HAVE BEEN DESIGNATED BY THE COMMISSIONER FOR THE NORTHWEST TERRITORIES AND BY THE MINISTERS OF ENVIRONMENT AND INDIAN AND NORTHERN AFFAIRS FOR CANADA ON MAY 29, 1984.

FLOODING MAY STILL OCCUR OUTSIDE OF THE DESIGNATED FLOOD RISK AREAS. THE COMMISSIONER AND THE MINISTERS DO NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS ON THIS MAP.

LES ZONES DE RISQUE D'INONDATION ET LE CANAL DE CRUE REPRÉSENTÉS SUR CETTE CARTE ONT ÉTÉ DÉSIGNÉES PAR LE COMMISSAIRE DES TERRITOIRES DU NORD-OUEST ET LES MINISTRES FÉDÉRAUX DE L'ENVIRONNEMENT ET DES AFFAIRES INDIENNES ET DU NORD EN VERTU DE L'ACCORD CANADA - TERRITOIRES DU NORD-OUEST CONCERNANT LA RÉDUCTION DES DOMMAGES DUS AUX INONDATIONS ET LES CARTES DE RISQUE D'INONDATION LE 29 MAI 1984.

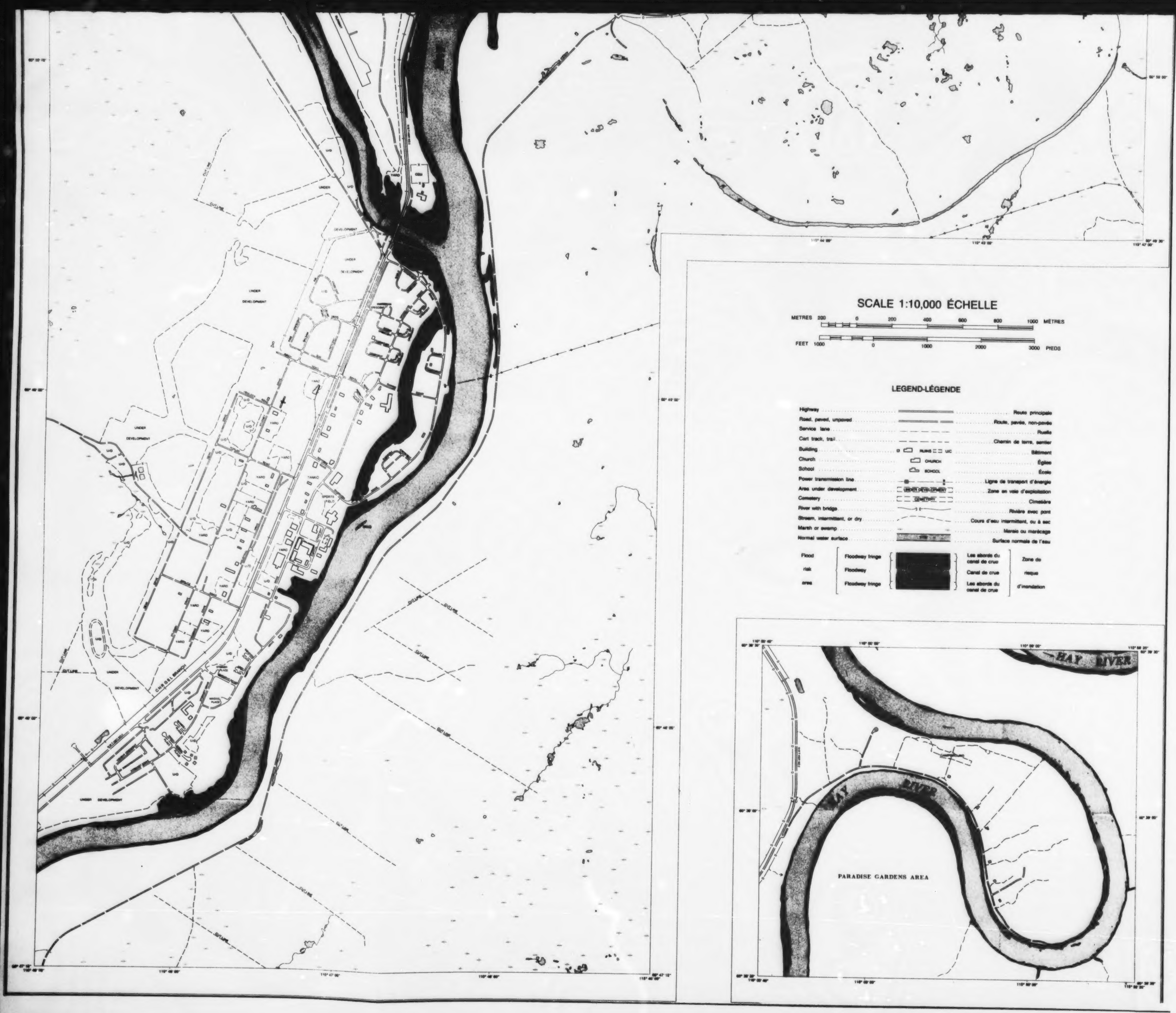
IL SE PEUT QUE DES ZONES EN DEHORS DE CELLES QUI ONT ÉTÉ DÉSIGNÉES SOIENT INONDÉES. LE COMMISSAIRE ET LES MINISTRES N'ASSUMENT AUCUNE RESPONSABILITÉ POUR AVOIR DÉSIGNÉ DU OMIS DE DÉSIGNER CERTAINES ZONES SUR CETTE CARTE.

THE HONOURABLE L'HONORABLE	CHARLES CACCIA, CANADA
THE HONOURABLE L'HONORABLE	JOHN MUNROE, CANADA
THE COMMISSIONER LE COMMISSAIRE	John H. Parker JOHN PARKER, NORTHWEST TERRITORIES

This map is for "GENERAL INFORMATION" only and has been derived from 1:2000 scale flood risk maps. For detailed information please consult the 1:2000 scale flood risk maps available at the following locations:

Community Office
or
The Department of Local Government,
Government of the Northwest Territories,
Yellowknife.

L'HONORABLE	
THE HONOURABLE L'HONORABLE	JOHN MUNROE, CANADA
THE COMMISSIONER LE COMMISSAIRE	John H. Parker JOHN PARKER, NORTHWEST TERRITORIES


UNDER DEVELOPMENT
YARD
U/C
CUT LINE
SPORTS FIELD
HAY RIVER
PARADISE GARDENS AREA

SCALE 1:10,000 ÉCHELLE

METRES 200 0 200 400 600 800 1000 MÈTRES

FEET 1000 0 1000 2000 3000 PIEDS

LEGEND-LÉGENDE

Highway	Route principale
Road, paved, unpaved	Route, pavée, non-pavée
Service lane	Ruelle
Cart track, trail	Chemin de terre, sentier
Building (RUINS, U/C)	Bâtiment
Church (CHURCH)	Église
School (SCHOOL)	École
Power transmission line	Ligne de transport d'énergie
Area under development (UNDER DEVELOPMENT)	Zone en voie d'exploitation
Cemetery (CEMETERY)	Cimetière
River with bridge	Rivière avec pont
Stream, intermittent, or dry	Cours d'eau intermittent, ou à sec
Marsh or swamp	Marais ou marécage
Normal water surface	Surface normale de l'eau

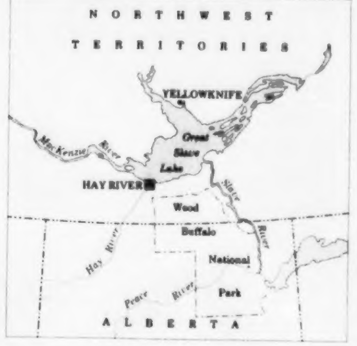
Flood	Floodway fringe	■	Les abords du canal de crue	Zone de
risk	Floodway	■	Canal de crue	risque
area	Floodway fringe	■	Les abords du canal de crue	d'inondation

This map is for "GENERAL INFORMATION" only and has been derived from 1:2000 scale flood risk maps. For detailed information please consult the 1:2000 scale flood risk maps available at the following locations:

Community Office
or
The Department of Local Government,
Government of the Northwest Territories,
Yellowknife.

Cette carte est conçue à des fins générales et provient de cartes de risque d'inondation à l'échelle de 1:2000. Des renseignements détaillés figurent sur les cartes de risque d'inondation à l'échelle de 1:2000 disponibles aux endroits mentionnés ci-dessus.

KEY PLAN LIEU DE LA CARTE


NORTHWEST
TERRITORIES
YELLOWKNIFE
Great Slave Lake
Mackenzie River
HAY RIVER
Wood Buffalo National Park
Hay River
Peace River
Slave River
ALBERTA

This map was prepared under the auspices of the Canada-Northwest Territories Flood Damage Reduction and Flood Risk Mapping Agreement signed May 2, 1979

Cette carte a été établie dans le cadre de l'entente, signée le 2 mai 1979, entre le Canada et les Territoires du Nord-Ouest sur la réduction des dommages dûs aux inondations et sur la cartographie des zones inondables.

RÉGION DE HAY RIVER AREA